THE INSTITUTION OF PRODUCTION ENGINEERS JOURNAL

APRIL 1956

THE INSTITUTION OF

PRODUCTION ENGINEERS JOURNAL

10 CHESTERFIELD STREET . LONDON . W1 Telephone : GROsvenor 5254/9

Vol. 35, No. 4 *Price 10/-* *April 1956*

CONTENTS

"Some Aspects of Automation in the Textile Industry" by A. G. Thompson, B.Sc., A.Inst.P., A.T.I. 201

The 1955 Sir Alfred Herbert Paper

"Work Design and Training for Future Industrial Skills" by N. H. Mackworth, M.B.Ch.B., Ph.D. 214

Report and Discussion 229

1956 Conference on Aircraft Production, Southampton, 6th/7th January

Conference Programme 241

Session III

"Control of Production Processes" by I. R. Smith 242

Report and Discussion 247

Session IV

"Machining Research and its Impact on Speeding Production" by D. A. Oliver, C.B.E., M.Sc.(Eng.), F.I.M.; T. S. Lister, B.Sc., A.I.M.; M. D. Kinman; and D. Fitzgeorge, Ph.D., A.M.I.Mech.E. 253

Report and Discussion 267

Conference Summing Up by The Rt. Hon. Lord Sempill, A.F.C., Hon.M.I.Prod.E., Past President of the Institution 274

The Institution of Production Engineers does not accept responsibility for any statements made or opinions expressed in any papers published in the Journal of the Institution.

Editorial Committee

M. Seaman—Chairman
Sir Leonard Lord, K.B.E.—President of the Institution
G. R. Pryor—Chairman of Council
H. G. Gregory—Vice-Chairman of Council
J. M. Brice
E. G. Brisch
A. A. Francis
B. G. L. Jackman
H. P. Jost
M. J. Sargeaunt
H. G. Shakeshaft
P. Spear
B. E. Stokes

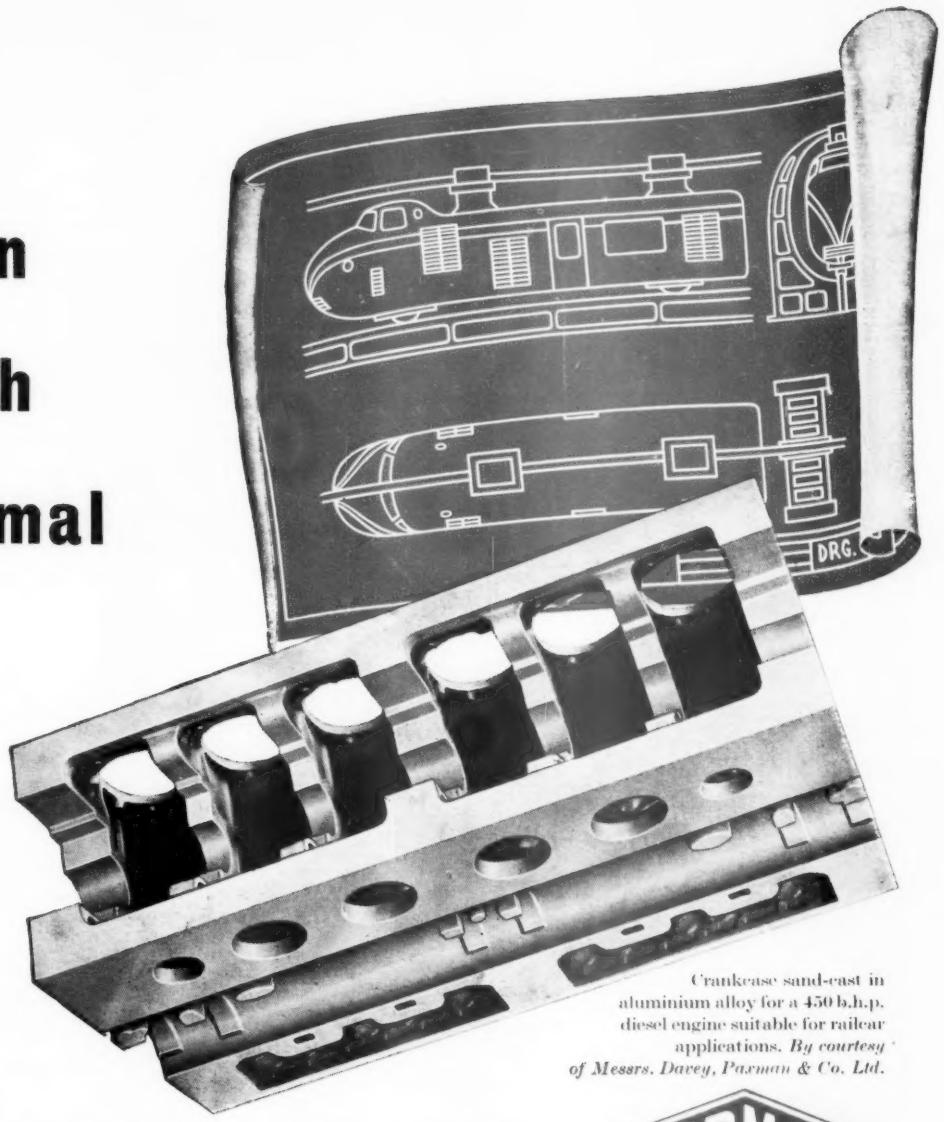
Editor

M. S. C. Bremner

Secretary of the Institution

W. S. F. Woodford

plan with Birmal



Crankcase sand-cast in aluminium alloy for a 450 b.h.p. diesel engine suitable for railcar applications. *By courtesy of Messrs. Davey, Paxman & Co. Ltd.*

You get more than a casting from BIRMAL

A plan is the link between past experience and future efficiency. Birmal can be called upon at the planning stage, and will provide the lessons and benefits of fifty-three years of casting experience.

Birmal service includes advice on the selection of materials and casting processes, a wide choice of specifications and foundry workshop co-operation.

Birmal supply aluminium and magnesium castings in sand, gravity die and pressure die casting.

Birmingham Aluminium Casting (1903) Co. Ltd.

BIRMID WORKS SMETHWICK BIRMINGHAM 40

Photograph by courtesy of British Insulated Callenders' Cables, Ltd.

Avo in action..

The checking of a busbar installation in a large steel works is an interesting example of the important contribution of the world-famous AvoMeter to the maintenance of electrical power plant. AvoMeters will be found wherever electricity is used in industry.

Model 40 *Universal* AvoMeter

A self-contained multi-range A.C./D.C. instrument providing 40 ranges of direct readings of current, voltage and resistance on a 5-inch hand calibrated scale fitted with an anti-parallax mirror. Range selection is by two rotary switches, for A.C. and D.C. respectively, and a press button provides additional ranges by halving the current and voltage ranges shown on the switch knobs. The total resistance of the meter is 200,000 ohms.

The instrument is compact and portable, and is protected by an automatic cut-out against damage through the inadvertent application of overload.

Power Factor and reactive kV.A. can be measured in A.C. circuits by means of an external accessory (the Universal AvoMeter Power Factor & Wattage Unit).

Size: 8 × 7¼ × 4½ ins.
Weight: 6½ lbs.

List Price **£19 : 10s.**

...you can depend on AVO

Sole Proprietors and Manufacturers.—
THE AUTOMATIC COIL WINDER & ELECTRICAL EQUIPMENT CO., LTD.
AVOCET HOUSE · 92-96 VAUXHALL BRIDGE ROAD · LONDON · S.W.1. *Telephone: VICtoria 3404 (9 lines)*

A40/3

Mitchell of KEIGHLEY – DARLING & SELLERS of KEIGHLEY

CENTRAL IRON WORKS · PARSON ST · KEIGHLEY

Makers of

"MITCHELL of KEIGHLEY"

6½" 8½" 10½" 12½" 14½" & 16½" CENTRE LATHES

Granor of HALIFAX

DUNKIRK MILLS
HALIFAX

Makers of

'GRANOR'
HEAVY DUTY LATHES
SURFACING & BORING LATHES
SHAPING MACHINES
SPECIAL PURPOSE LATHES
and
'GRANOR'
BREAK LATHES

RUSHWORTH of SOWERBY BRIDGE

GLOUGH WORKS
SOWERBY BRIDGE

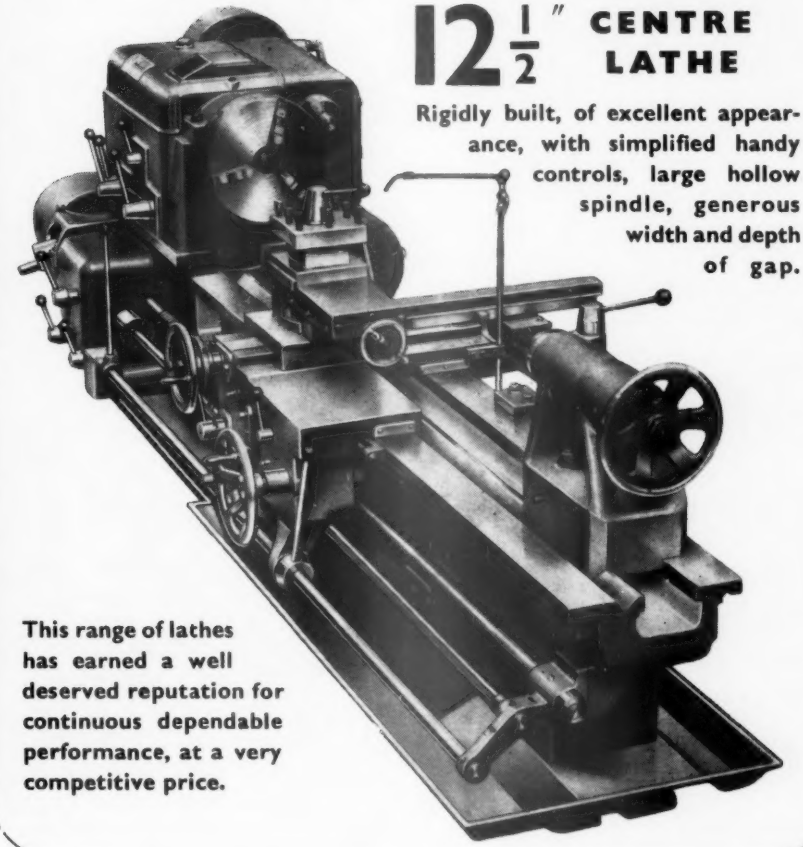
Makers of

GUILLOTINES
PRESS BRAKES
PLATE BENDING AND STRAIGHTENING ROLLS

Mitchell of KEIGHLEY

12½" CENTRE LATHE

Rigidly built, of excellent appearance, with simplified handy controls, large hollow spindle, generous width and depth of gap.



This range of lathes has earned a well deserved reputation for continuous dependable performance, at a very competitive price.

LONDON AND EXPORT OFFICE

MORRISON, MARSHALL & HILL LTD., 44/45 TOWER HILL, LONDON, E.C.3

Telephone: ROYAL 1461. Cables: Morimil, London. Telegrams: Morimil, Fen, London

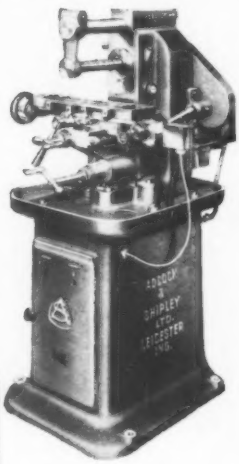
increased production

with our

size 'O'
HORIZONTAL MILLING MACHINES

- 12" × 5" or 18" × 5" Table size
- Lever Hand Feed
- Screw Hand Feed
- Normal Automatic Feed
- Semi-Automatic Cycle Feed
- Five Speed Ranges

INTERESTED IN SMALL COMPONENT MILLING? Then there is a machine for you within our SIZE 'O' range. Eighteen different models varying in speed ranges (150 r.p.m. minimum or 4000 r.p.m. maximum) or type of feed. For economy, speed and ease of operation just the type of machine you need.



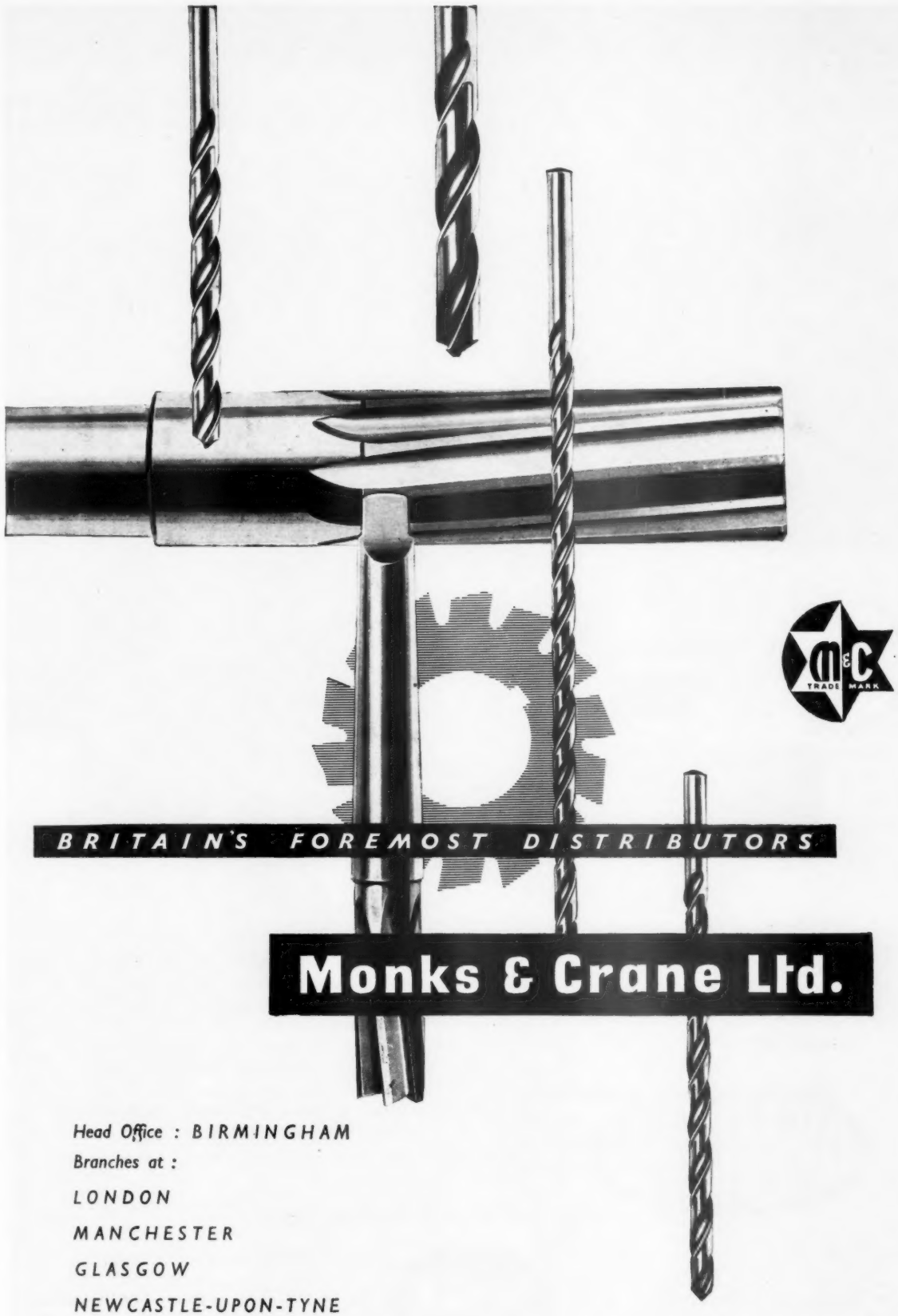
The Model OAD with Multi-form (Semi-Automatic Cycle) Feed and 12 speeds from 150 r.p.m. to 3000 r.p.m.

ADCOCK & SHIPLEY LTD.

P.O. BOX 22 : ASH STREET : LEICESTER

Telephone: Leicester 65154/6

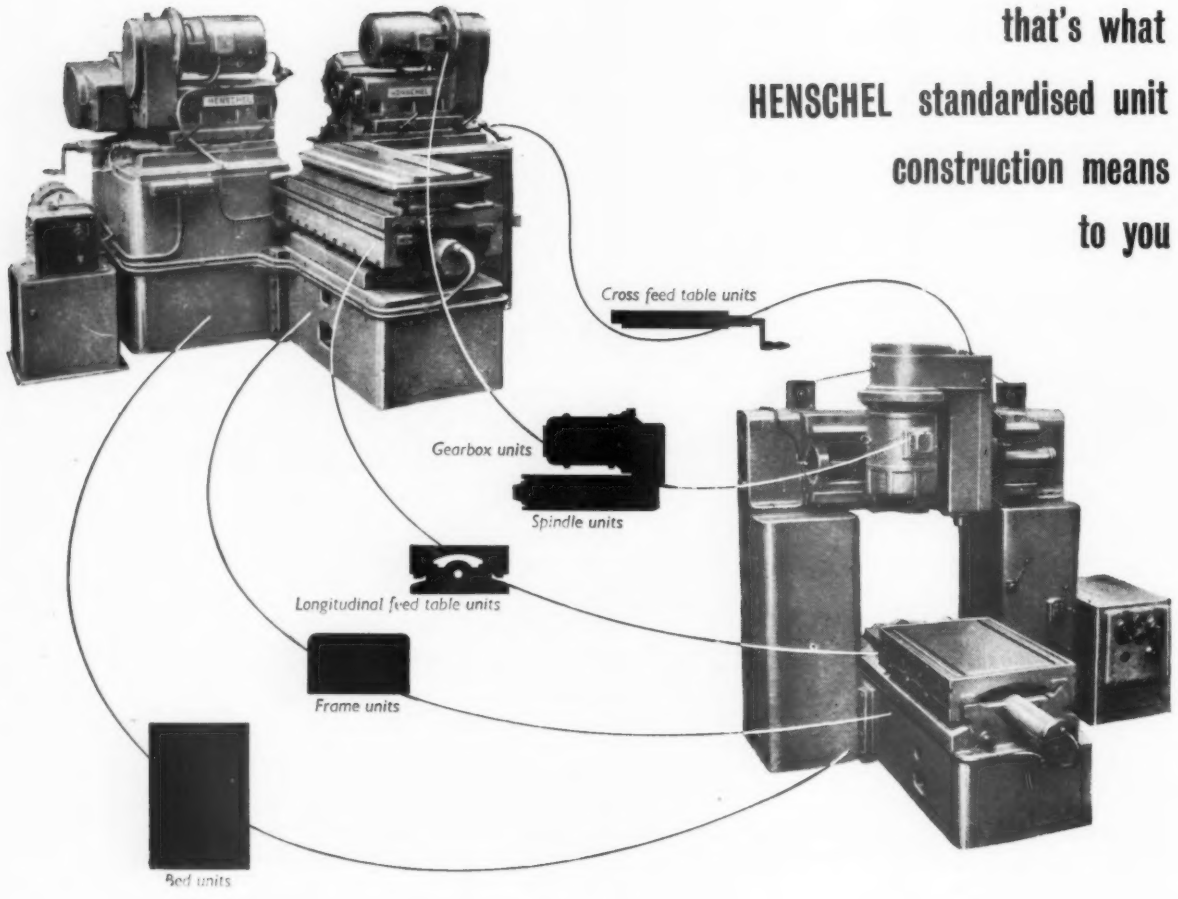
Telegrams: "Adcock" Leicester


M&C
TRADE MARK
BRITAIN'S FOREMOST DISTRIBUTORS
Monks & Crane Ltd.
Head Office : BIRMINGHAM
Branches at :
LONDON
MANCHESTER
GLASGOW
NEWCASTLE-UPON-TYNE

Special purpose machine tools

IN LESS TIME AT LESS COST...

that's what HENSCHEL standardised unit construction means to you



This illustrates a surface milling machine and a 2-spindle plano-milling machine

Henschel units are available for

MILLING - DRILLING - BORING
MULTIPLE BORING - COUNTER BORING
REAMING - THREADING & TAPPING

Normally, if you want a special purpose machine tool it costs a great deal of money and, being specially built from scratch, takes a long time for delivery. The Henschel unit construction system alters all that; it leads directly to lower cost and quick delivery, for the necessary units are always available "off the shelf" for Henschel-built machines.

May we tell you more about this progressive idea?

MACHINE SHOP EQUIPMENT LTD. MSE Spenser St., London, S.W.1. Tel.: VICtoria 6086

From every melt of incoming metal and through every stage of manufacture, Unbrako Screws are subjected to material, dimensional and physical laboratory tests that leave nothing to chance. You can use smaller screws or less screws when you specify Unbrako, that's why they are used in ever increasing quantities by industry throughout the world.

UNBRAKO

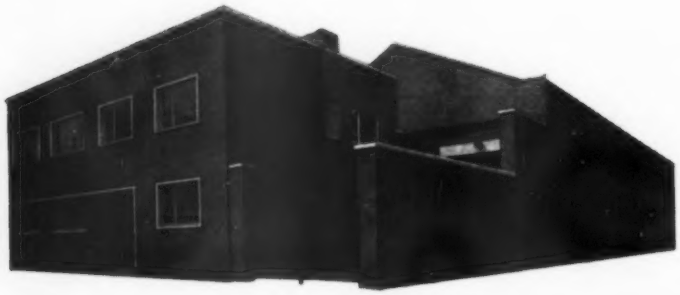
UNBRAKO SOCKET SCREW CO., LTD., COVENTRY

Stanley Howard

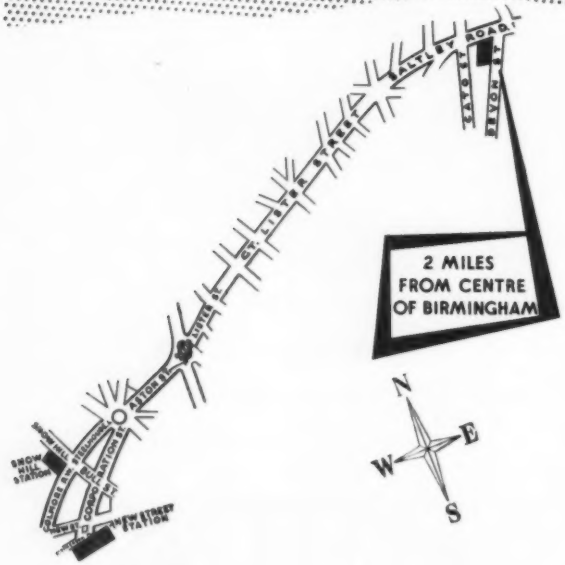
extends a cordial invitation to inspect

***the very extensive range of* MACHINE TOOLS**

***at his* NEW SHOWROOMS.**



We should be very happy to discuss YOUR particular machine tool requirements and demonstrate some of the machines we now have on show. Details of some of the leading makes, for which we are agents, are listed below.



Special Purpose machines—
by Bammesberger & Co.

Fine Boring machines—
by Boneham & Turner Ltd.

Cylinder Boring machines—
by Deragne Freres.

Shellmoulding machines, tracing and copying units—
by Fairbairn Lawson Combe Barbour Ltd.

Plain and Universal Grinders—
by Gendron Freres.

Jig Boring machines—
by Hermann Kolb.

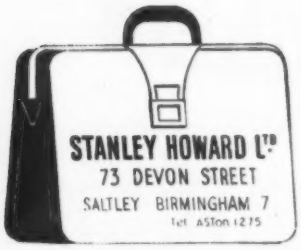
Optical Rotary Tables—
by Schenk & Co.

Plain and Automatic Internal Grinding machines—
by Maschinenfabrik Spandau.

Tooth Rounding machines—
by Stenzel & Co.

Vertical Multispindle Automatics, Horizontal Single Spindle Automatics—
by Tavannes Machines Co.

Plain, Vertical and Universal Milling machines—
by Wanderer-Werke.



SPECIAL PURPOSE MACHINES

FOR ALL INDUSTRIES

To their world-renowned range of MORRISFLEX Flexible Shaft and Polishing Shop equipment B. O. Morris Limited, of Coventry have now added :—

SEMI-AND/OR FULLY AUTOMATIC POLISHING, BUFFING, BRUSHING AND FETTLING MACHINES

designed specifically for individual operations to the special requirements of every branch of industry and in particular that engaged in the manufacture of Motor Car Accessories.

These Special Purpose Machines possess three very important advantages :—

1. **A CONTROLLED AND THEREFORE CONSTANT FINISH**
2. **A SKILLED RESULT FROM SEMI-OR UN-SKILLED HANDS**
3. **A SOLUTION TO THE PROBLEM OF LABOUR SHORTAGE**

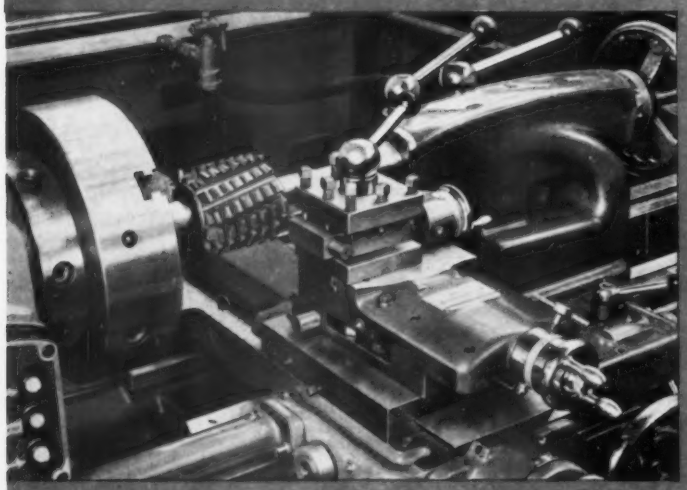
B. O. Morris Limited, will be pleased to place their unrivalled polishing and finishing technique together with their specialised engineering experience and resources at your disposal.

Morrisflex

B. O. MORRIS LTD., MORRISFLEX WORKS, BRITON ROAD, COVENTRY
Telephone: COVENTRY 5081 Telegrams MORRISFLEX, COVENTRY, ENGLAND

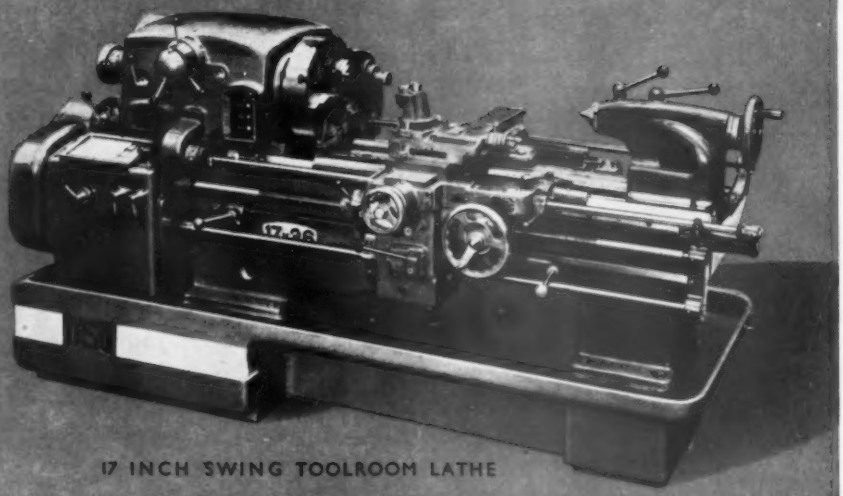
internationally famous for accuracy and...

PRECISION



RELIEVING ATTACHMENT

- READILY DISENGAGED FOR NORMAL TURNING.
- ONE CAM GIVES VARIABLE RELIEF.
- RELIEVING ATTACHMENT IS BUILT AS AN INTEGRAL PART OF THE MACHINE.



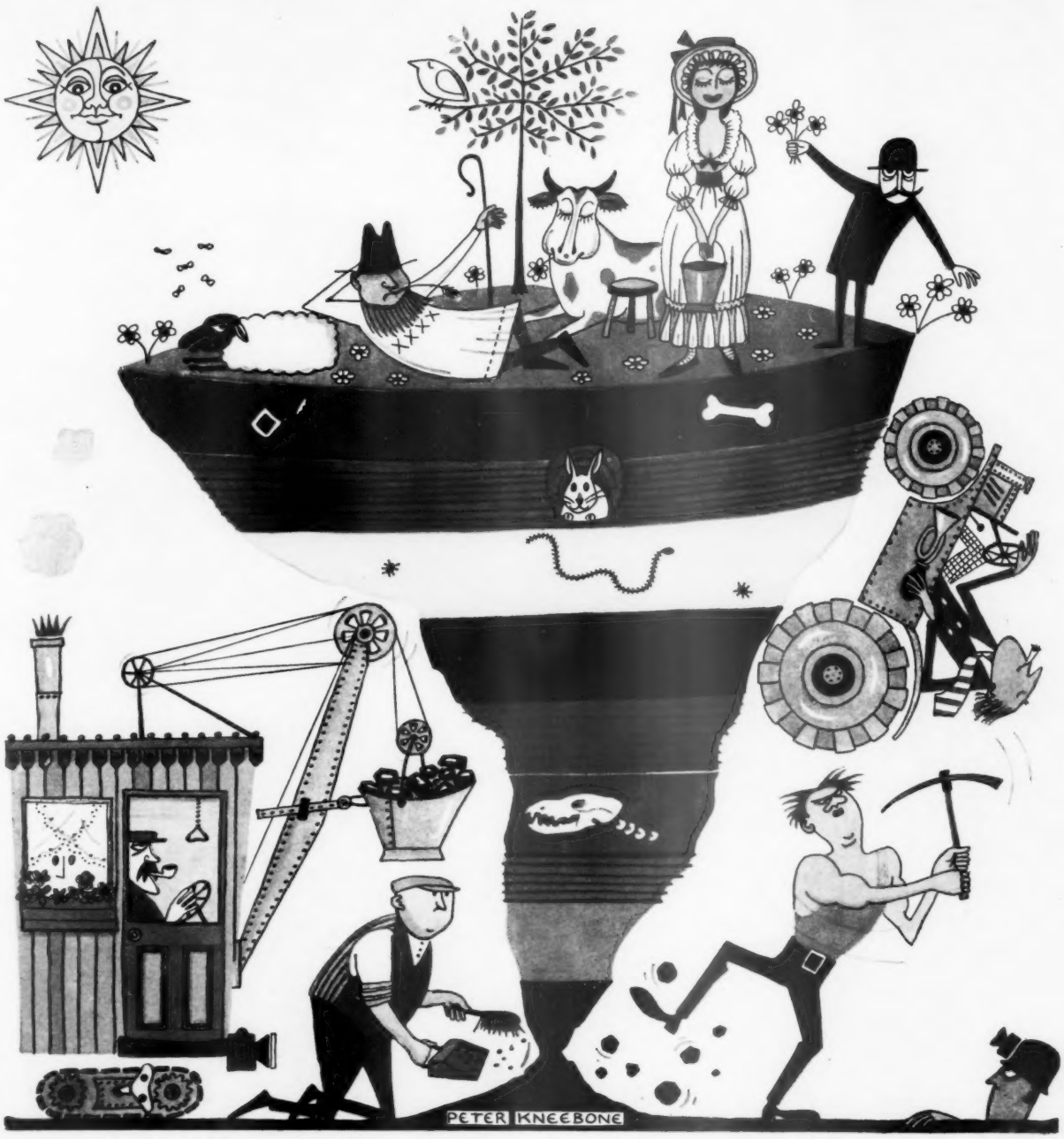
17 INCH SWING TOOLROOM LATHE

INTERNATIONAL MACHINE TOOL EXHIBITION 1956
June 22-July 6
Olympia · London

Dean Smith & Grace
KEIGHLEY LIMITED ENGLAND

We manufacture... 13"-30" SWING ENGINE LATHES · SURFACING & BORING LATHES · TOOLROOM LATHES

DESCRIPTIVE LITERATURE SENT ON REQUEST



Oiling the wheels of industry—

OPEN-CAST MINING

For every modern industrial process there is a specialised grade of Sea Shell Lubricant.

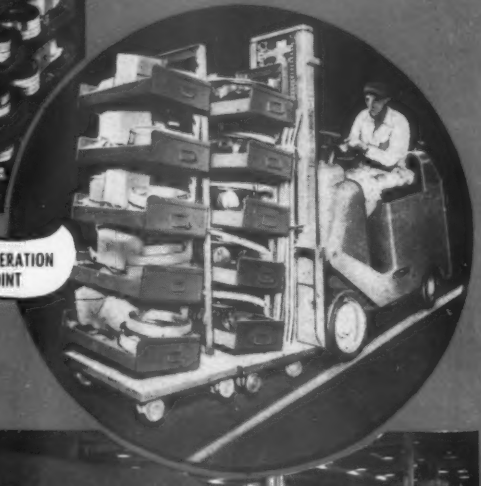
SHELL **leadership in lubrication**

Copies of this advertisement (in colour) can be obtained from Shell-Mex and B.P. Ltd.

RACK CONVEYORS saved 1235 man-hours per month!

...and paid for themselves in 60 DAYS

Typical of many RACK installations throughout industry



CONTROLLED MATERIALS PLACEMENT *helps speed Assembly and Machining*

THE movement of sets of related parts, step by step, from stock room to point of final assembly, by Rack Conveyors, is shown in these pictures. Note that the material is sorted and placed on Rack Conveyors in workable order, creating a portable bank for servicing operation points.

Thus *controlled materials placement* avoids loss of time and confusion and helps speed production!

Write for information on Rack Conveyors for your particular shop procedure, whether for handling, moving or processing.

Over 300 Leading Manufacturers Use

Rack CONVEYOR SYSTEMS

6 of the 18 Rack Units Available

• *See how easy it is to locate parts and how accessible they are to operator . . . nothing on the floor, everything within reach, no duplicate handling!*

MADE IN ENGLAND

RACK ENGINEERING LIMITED
9 CAMOMILE STREET LONDON, E.C.3, ENGLAND

CARBORUNDUM
Cut Grinding Costs

A grinding operation in the production of garden shears. Using an ALOXITE resin industrial cloth belt, 4″×136″, and a "61" Contact Wheel by CARBORUNDUM, production has been trebled, and running costs have been considerably reduced.

Progressive manufacturers acknowledge the superiority of coated abrasives by CARBORUNDUM. They have turned to products by CARBORUNDUM for grinding and polishing in preference to set-up wheels and dressed mops.

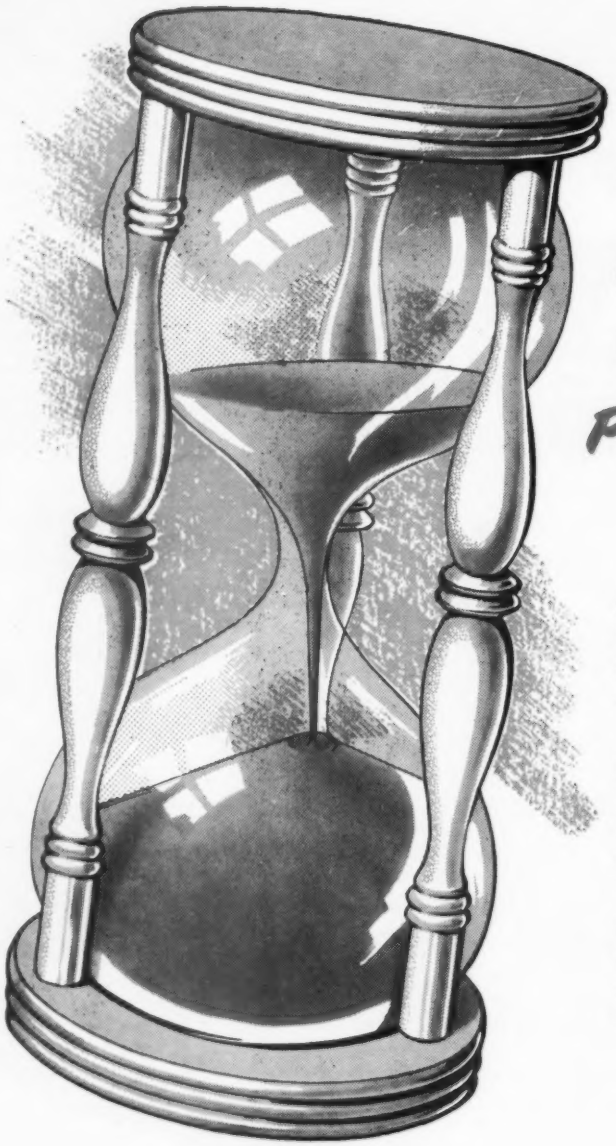
We should be very pleased to demonstrate to you. We are absolutely confident that the "61" Contact Wheel, used with an abrasive belt by CARBORUNDUM, will cut your grinding costs and increase your production.

ALOXITE is a registered trade mark of The Carborundum Company Limited

THE CARBORUNDUM CO. LTD. MANCHESTER

FASTER—WORKING, LONGER—LASTING
Coated-abrasive products by CARBORUNDUM

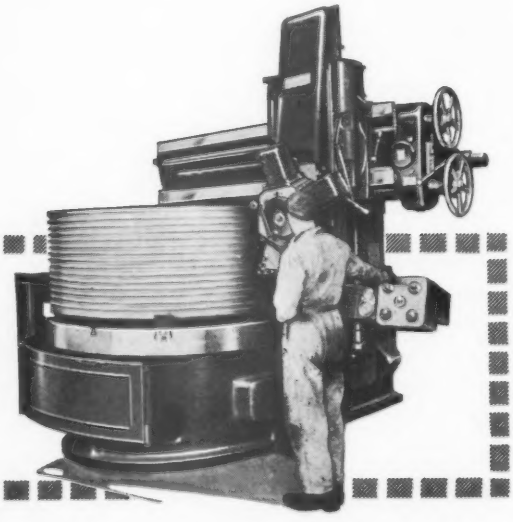
THE CARBORUNDUM COMPANY LTD., TRAFFORD PARK, MANCHESTER 17. PHONE: TRAFFORD PARK 2381



A COMPANY IS KNOWN BY THE CUSTOMERS & PROMISES IT KEEPS

Although the world-wide reputation enjoyed by the Webster and Bennett Boring Mill is based on inherent quality and fitness for purpose there are other aspects of service of equal importance.

One of those which is of particular pleasure and satisfaction to our customers, and a source of pride to ourselves, is a punctilious observance of delivery dates. No effort is spared to meet a promised delivery and although unforeseen circumstances have frequently arisen, sufficient in themselves to justify a delivery extension, deliveries quoted for machines have never been broken.



The illustration shows a Webster and Bennett 60″ Boring and Turning Mill at the Bradford Works of Crofts (Engineers) Ltd., machining a 60″ diameter vee groove pulley with a face width of 26″ having 18 grooves 1¼″ wide by 1¼″ deep.

WEBSTER & BENNETT LTD., COVENTRY, ENGLAND

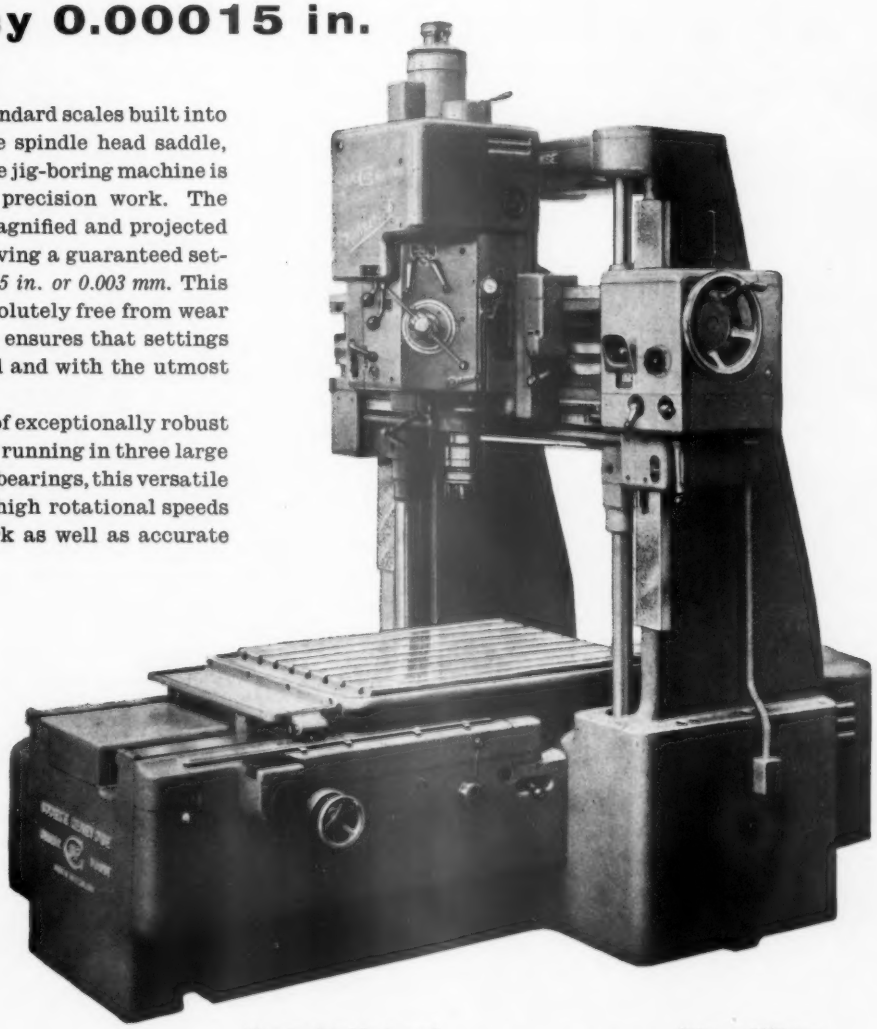
guaranteed

Hydroptic 6

accuracy 0.00015 in.

With high precision standard scales built into the work-table and the spindle head saddle, this extremely accurate jig-boring machine is capable of very high precision work. The scales are optically magnified and projected onto *viewing screens*, giving a guaranteed setting accuracy of *0.00015 in. or 0.003 mm.* This measuring system, absolutely free from wear and mechanical stress, ensures that settings are performed at speed and with the utmost simplicity.

With the spindle head of exceptionally robust design, and the spindle running in three large pre-loaded taper roller bearings, this versatile machine is capable of high rotational speeds for heavy milling work as well as accurate jig-boring.



The installation and service of this machine is carried out by the area Engineers of Sogenique (Service) Ltd., under the GSIP guarantee. For literature or further information please write, or telephone Temple Bar 2126.

HYDROPTIC 6

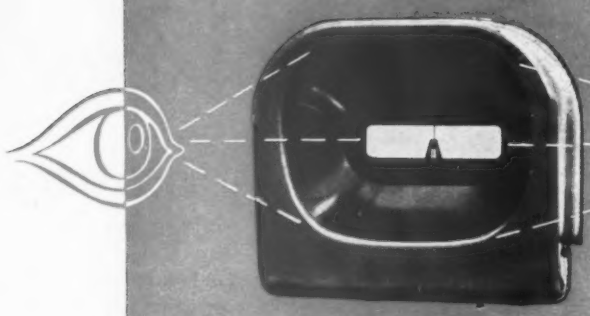
Nominal table travel	40 in. — 1000 mm.
Nominal spindle head travel	28 in. — 700 mm.
Maximum distance from table top to spindle end	35½ in. — 900 mm.
18 spindle speeds	from 40 to 2000 rpm.
GUARANTEED ACCURACY FOR ALL SETTINGS OF WORK-TABLE AND SPINDLE HEAD	*0.00015 in. — 0.003 mm.*

GSIP

Société Genevoise Ltd

5-6 BRETTENHAM HOUSE LANCASTER PLACE LONDON W.C.2.

ACCURACY at a glance



This jig boring machine having large capacity performance incorporates built-in standard scales ensuring permanent accuracy of all co-ordinate settings.

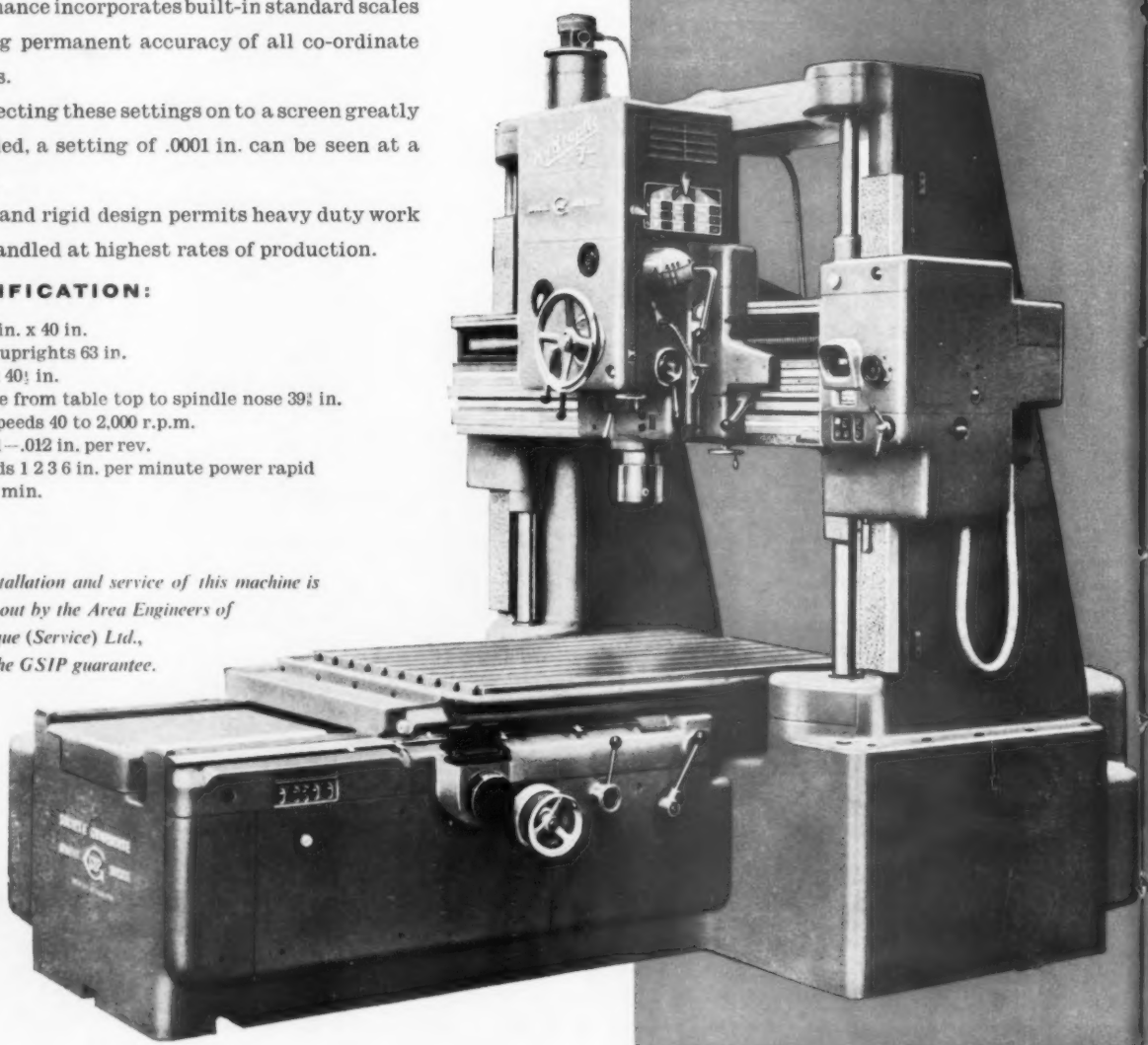
By projecting these settings on to a screen greatly magnified, a setting of .0001 in. can be seen at a glance.

Strong and rigid design permits heavy duty work to be handled at highest rates of production.

SPECIFICATION:

Working range 55 in. x 40 in.
Distance between uprights 63 in.
Table size 61½ in. x 40½ in.
Maximum distance from table top to spindle nose 39¾ in.
Vertical spindle speeds 40 to 2,000 r.p.m.
8 spindle feeds .001—.012 in. per rev.
Power milling feeds 1 2 3 6 in. per minute power rapid traverse 58 in. per min.

The installation and service of this machine is carried out by the Area Engineers of Sogenique (Service) Ltd., under the GSIP guarantee.



GSIP

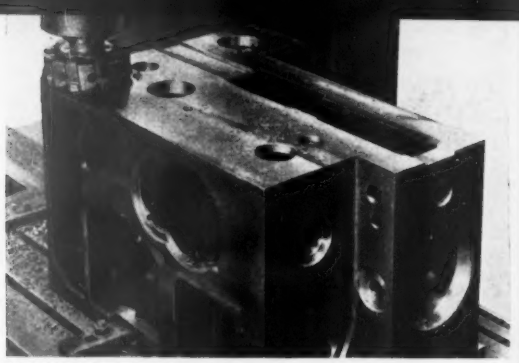
HYDROPTIC 7P

Guaranteed setting accuracy .0002 in.

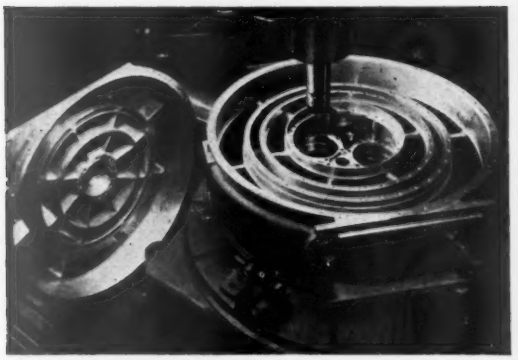
Settings are performed with amazing speed and utmost simplicity.

Approximate settings are provided by external scales divided into 0.1 in. Further decimal figures are read to 0.0001 in. on the micrometer head of each viewing screen the movements of which control the position of the reticle on the screen. Slow motion controls of the table and spindle saddles enables accurate settings to be obtained by centering the appropriate projected standard scale line between the indices of the reticle.

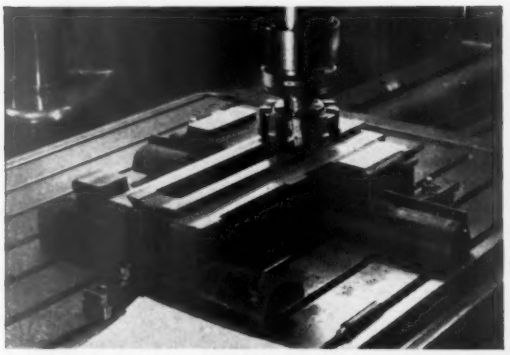
For literature or further information please write or telephone Temple Bar 2126.



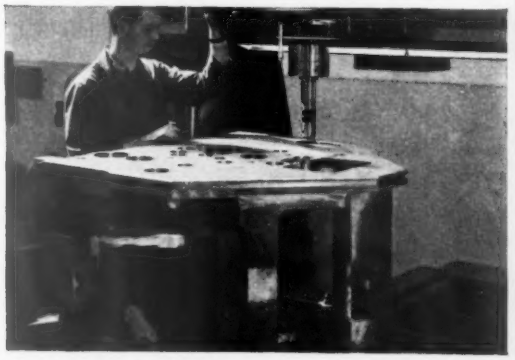
Milling a headstock, fully machined on the 7P.



Boring light alloy gear reduction housing for jet engines.



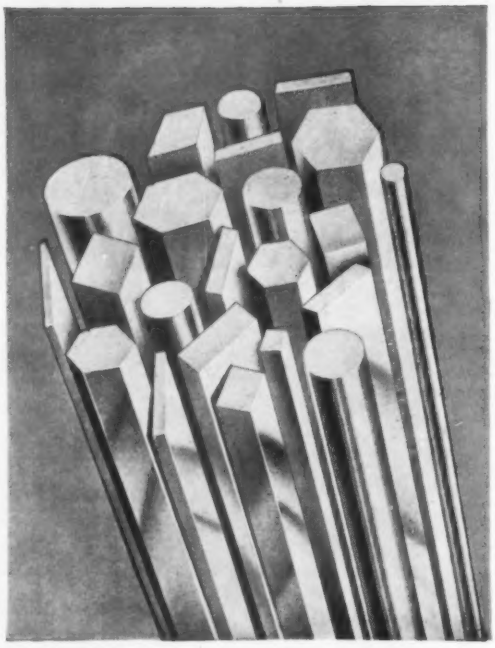
Milling a large lathe cross-slide, saving hand-scraping.



Machining a housing fully machined on the 7P.

SOCIETE GENEVOISE LTD

5-6 BRETTENHAM HOUSE · LANCASTER PLACE · LONDON W.C.2



The best bright steel bars——bar none!

As steel stockholders Macready's Metal Company meet the pressure of an intensely competitive industry with stream-lined service and the highest quality stocks.
Twenty well known lines are handled in the large and efficiently planned warehouse in Pentonville Road, ensuring fast delivery and exact response to the customer's specifications.
Known throughout the steel industry, Macready's Usaspead Service is a guarantee of quality, accuracy, and prompt delivery.

BRITISH 100% AND BEST

MACREADY'S METAL COMPANY LTD

London's Leading and Largest Steel Stockholders

"Usaspead" Corner, Pentonville Road, London, N.1 · Tel: TERminus 7060 (20 lines). Telegrams: Usaspead, London. Telec. 2-2788

PROMPT · RELIABLE · DEPENDABLE SERVICE LARGE LONDON STOCKS

THE PHYSICAL SOCIETY

40th EXHIBITION

of

* *New scientific instruments & apparatus*

MAY 14TH—17TH

AT THE OLD & NEW HALLS
ROYAL HORTICULTURAL SOCIETY
WESTMINSTER

OPENING CEREMONY AT 11.0 A.M. BY SIR JOHN COCKCROFT, K.C.B., K.B.E., F.R.S.

HOURS OF OPENING

Monday May 14th	10.30 a.m.—8.0 p.m. (10.30 a.m.—2.0 p.m., Press and Members only).
Tuesday May 15th	10.0 a.m.—8.0 p.m.
Wednesday May 16th	10.0 a.m.—8.0 p.m.
Thursday May 17th	10.0 a.m.—5.0 p.m.

* **For details of Exhibits,** see official Exhibition Handbook, Price 6/- (Postage Extra) from The Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7.

DISCOURSES

Monday May 14th	**Recent Developments in in Light Sources,** by H. G. Jenkins
Tuesday May 15th	**The Production of Images of Chemical Molecules,** by H. Lipson
Wednesday May 16th	**Colour Television, Considerations which have led to Recent Trends,** by G. G. Gouriet

Admission free by ticket only

BUILT FOR ROUND-THE-CLOCK SERVICE

—year in

—year out

HOLMAN T60R COMPRESSOR

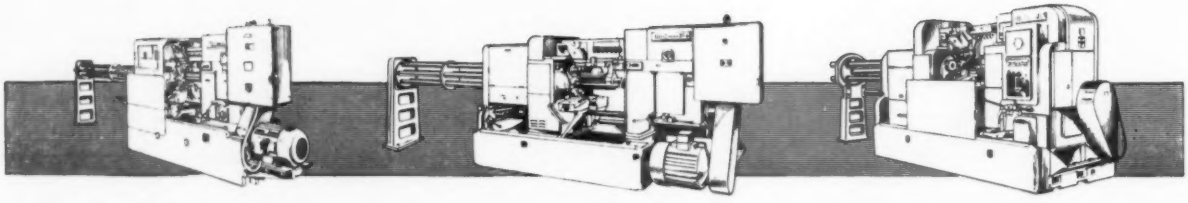
The Holman T60 R two-stage compressor ("closed circuit cooling package unit") is specifically designed for use where there is no constant water supply, but in fact its application is almost universal. Thanks to its compact design (notice the lack of external pipework) and self-contained cooling system, it is readily transportable and easily installed in a corner of a factory or store-room, in the basement of a building, in underground workings — or flown to remote sites. F.A.D. 535 c. ft. Built for constantly reliable service under all conditions, the T60 R is another fine Holman contribution to productivity in industry. May we send details ?

FOR INCREASING PRODUCTIVITY **Holman**

ROCK DRILLS · COMPRESSORS · PNEUMATIC TOOLS

HOLMAN BROS. LTD., CAMBORNE, ENGLAND. *Telephone* : CAMBORNE 2275 (10 lines). *Telegrams* : AIRDRILL, CAMBORNE HES

2⅝" — 6 Cycle times 7·1—922 secs.
Spindle speeds 80—1000 r.p.m.



1" — 6 Cycle times 2—133 secs.
Spindle speeds 247—3030 r.p.m.

2" — 6 Cycle times 7—602 secs.
Spindle speeds 111—1302 r.p.m.

3½" — 4 Cycle times 9—923 secs.
Spindle speeds 60—800 r.p.m.

RANGE of BAR and CHUCKING

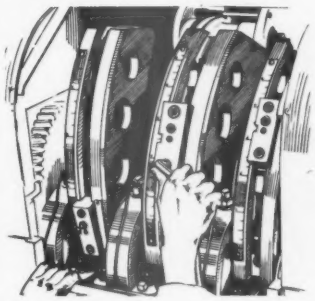
Automatics

Throughout the World, production engineers whose daily concern is the high-speed output of turned metal parts are looking to automatic equipment for the solution to the insatiable and unprecedented demands of the mass-producing industries.

More and more are finding the solution in the Wickman range of multi-spindle automatics. With a background of nearly twenty years development and a fine record of high-production service to the metal-working industries these machines offer an immediate and lasting solution to the problem of rising labour costs, higher overheads, and the handicap of limited factory space.

Universally recognised as the most accurate machines of their class, fast, and versatile, and with a wide range of supplementary attachments, their scope of application covers the field of repetition production up to 3½″ diameter for bar work, and up to 9″ diameter for castings, forgings and other chucked components.

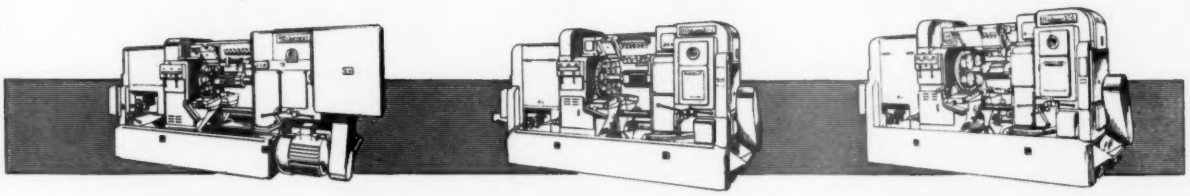
The incorporation of the exclusive Wickman autosetting mechanism enables tool slide feed strokes to be set by the simple adjustment of sliding levers against graduated scales, and without changing cams. The feature reduces setting-up and change-over times and permits fast automatic production to be employed for the economic machining of small and medium batch quantities.



Wickman

WICKMAN LIMITED

MACHINE TOOL DIVISION · BANNER LANE · COVENTRY · ENGLAND



6⅝″ — 6 Cycle times 10·6—1297 secs. Spindle speeds 78—1302 r.p.m.

7¼″ — 6 Cycle times 10·9—1408 secs. Spindle speeds 77—1004 r.p.m.

9″ — 4 Cycle times 17·7—1968 secs. Spindle speeds 43—554 r.p.m.

438WM.

Cold impact extrusion

... the fastest metal-forming technique

Cold impact extrusion is a fast and economical method of producing hollow containers and complex shapes in non-ferrous and certain ferrous materials.

Save cost and material

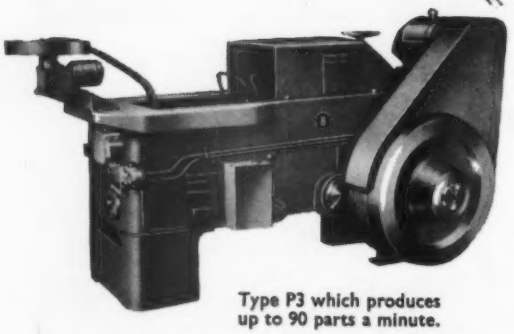
Many components now used in industry and produced by a variety of other processes, lend themselves to production by impact extrusion with consequent saving in cost and material. This cold forming process induces added strength in parts by utilising the grain flow, and produces a smooth and flawless finish.

For mass-production

Herlan presses mass-produce accurate extrusions, and machines are available with production rating from 35 to 95 parts a minute. Extrusions up to $4\frac{3}{4}''$ diameter (aluminium) at a wall thickness of 0·011″ and maximum length of $12\frac{3}{4}''$ may be obtained from these versatile machines.

Automatic operation

The presses are entirely automatic, and after loading, feed, form, strip-off and eject in rapid sequence. The horizontal working stroke is absolutely smooth and bottom thickness can be adjusted while the press is in motion. Shockless operation promotes long tool life and provision for rapid tool change provides maximum flexibility.



Type P3 which produces up to 90 parts a minute.

HERLAN
EXTRUSION PRESSES

INTERNATIONAL MACHINE TOOL EXHIBITION 1956
June 22-July 6
Olympia · London

Wickman

WICKMAN LIMITED

FACTORED MACHINE TOOL DIVISION · FLETCHAMSTEAD HIGHWAY COVENTRY

Telephone Coventry 40351

435F83

CLASSICS OF CRAFTSMANSHIP

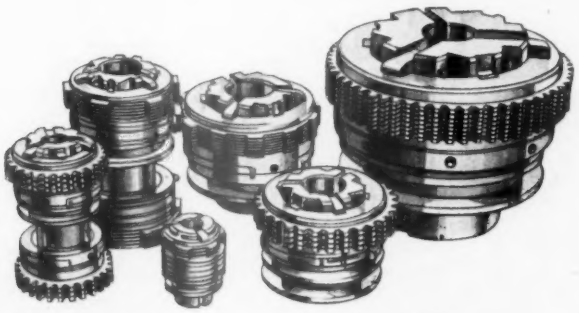
An inspiration to the modern quest for perfection

HERCULANEUM, NAPLES, ITALY

Buried by an eruption of Mount Vesuvius in A.D. 79, which sealed and so preserved much of the detail, the excavations reveal the high degree of Greco-Roman civilisation.

MATRIX
COVENTRY GAUGE & TOOL COMPANY LTD.

MACHINE TOOLS
PRECISION INSTRUMENTS & GAUGES
PRECISION TOOLS OF ALL TYPES



Multi-disc Clutches

Supreme the World over

Coventry Gauge & Tool Co Ltd
COVENTRY GT. BRITAIN

Cogent.

Wimet CLAMPTIP TOOLS offer even longer life from carbide tools

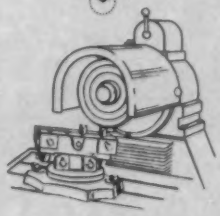
The Wimet range of Clamptip tools offers users the benefits of improved tool performance, infinitely longer carbide life, and a variety of tooling possibilities.
These tools may be used in any combination one with another or incorporated with standard tools in a set-up.

STRESS-FREE SOLID INSERTS

Tool performance is improved since the solid carbide inserts are secured entirely by mechanical means and thus remain free from the stresses usually inherent in brazed tools.

MULTIPLE CUTTING POINTS

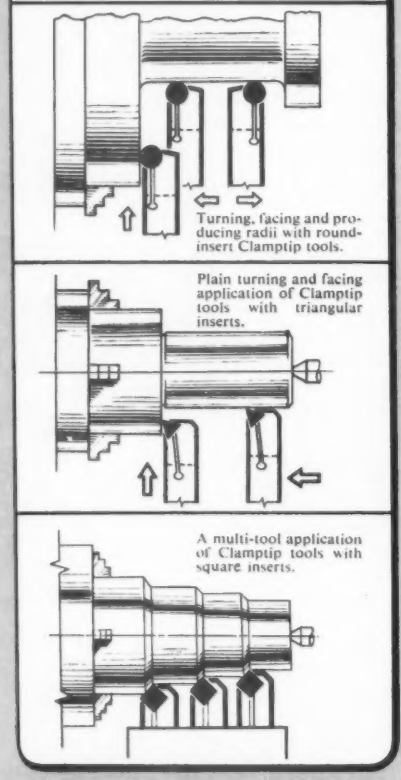
When cutting edges become dulled, the insert can be repositioned in its holder. Only when all edges have been so used is it necessary to remove for resharpening.



SIMPLIFIED RESERVICING AND UNDISTURBED TOOL SETTINGS

In multi-tool set-ups the use of Clamptip tools enables tool settings to remain undisturbed when carbide inserts require removal for reservicing. At the end of the long carbide life of the tool, the insert is replaced with another of standard size (alternatively, the remaining unused carbide may be brazed to a steel insert when the fullest possible service may then be obtained from the Wimet).

Typical applications



Turning, facing and producing radii with round-insert Clamptip tools.

Plain turning and facing application of Clamptip tools with triangular inserts.

A multi-tool application of Clamptip tools with square inserts.

Made in Three Types

Wimet Clamptip Tools are made with round, square, or triangular inserts in a range of sizes of each type. Inserts are available in grades of Wimet recommended for roughing or finishing cuts on either cast iron and non-ferrous materials or steels.

Write to-day for your copy of the Wimet Clamptip Tools leaflet. It contains full details of all types, sizes, and grades of Wimet inserts available.

WICKMAN *of* COVENTRY

WICKMAN LIMITED, WIMET DIVISION, TORRINGTON AVENUE
COVENTRY, ENGLAND. *Telephone:* Tile Hill 66621

Wickman

348ST.

The Institution of Production Engineers Journal
VOL. 35 NO. 4 APRIL, 1956

SOME ASPECTS OF AUTOMATION IN THE TEXTILE INDUSTRY

by A. G. THOMPSON, B.Sc., A.Inst.P., A.T.I.

Mr. Thompson

Mr. Thompson, who has written this Paper specially for the Journal, is responsible for technical development in a group of manufacturing units within the Tootal Organisation.

After taking an honours degree in Physics at Manchester University in 1947, Mr. Thompson joined the Research Department of Tootal Broadhurst Lee Co. Ltd., where he was mainly concerned with fundamental problems associated with manufacturing processes. In April, 1953, he was appointed to his present position.

Mr. Thompson was elected an associate of the Institute of Physics in 1950 and became an associate of the Textile Institute in 1952. For the past five years he has served on the Committee of the Manchester and District branch of the Institute of Physics, and since 1954 he has been a member of the Warrington and District Productivity Committee.

THE beginnings of automation can be traced to the early efforts of inventors to produce mechanisms which would minimise the amount of human effort required to carry out the many tedious processes which are to be found in the early days of almost any industry. In this respect, the Industrial Revolution gave the textile industry an excellent start.

In 1773, John Kay developed his flying shuttle which enabled the weaver to send the shuttle from one side of the loom to the other using one hand only. This invention not only enabled the weaver to increase his production, but also made it possible for a single weaver to look after one wide loom, whereas previously, one man had been required at each side ; twenty years later, the flying shuttle was in common ues in Lancashire. The demand for yarn caused by the increase in productivity of the weaving section of the industry influenced the development of Hargreaves Spinning Jenny in 1767. This machine, which simulated the action of the spinner's hand, made it possible for the first time for a spinner to look after more than one spindle. The year 1769 saw the introduction of Arkwright's spinning frame, a machine carrying two sets of rollers which moved at different speeds. The action of these rollers was to draw out the yarn into a fine thread. The twist was then inserted and the thread was taken up by the spindle. Arkwright's spinning frame was the first of many automatic machines which were to transfer the industry from the cottage to the factory.

There was a further marked advance in 1779 when Samuel Crompton, incorporating the work of Arkwright and Hargreaves, produced a machine which later became known as the mule ; although initially worked by hand, it embodied principles of spinning still used to this day. Six years later Watts steam engine was used for the first time in a cotton mill, and as more and more steam engines were

installed, more and more mule frames came into use.

The developments in spinning had outstripped those in weaving, but in 1785 Cartwright invented the first power loom which was mechanically crude and slow in gaining acceptance. However, as warp preparation improved, and mechanical improvements were carried out to looms, the weaving section of the industry began to grow — in 1813 there were 2,400 looms, but by 1833 the number had risen to 100,000. It was during this period (1801) that Joseph Marie Jacquard demonstrated his loom controlled by punched cards.

All these inventions, which at that time represented very advanced mechanisation, not only changed the power, but also the character of the industry: spinning, which was formally done by "spinsters" in their own homes, was now being done by men in the factories, and with the advent of the power loom, women gradually replaced men as weavers.

The Structure of the Industry

It has often been said that the cotton industry has lost most of its early lead in the realm of mechanisation; however, it is interesting to examine how the industry expanded after the Industrial Revolution, as this has a marked bearing on the further application of automatic machinery.

From about 1830 the cotton industry began to fall into a definite pattern which was to persist until the early years of the twentieth century. Spinning obviously required large buildings and relatively expensive machinery and so there was a tendency for the typical spinning mill to be of a medium size operated by a public company. On the other hand, weaving could be carried out by anyone who had sufficient space and capital to buy a few Lancashire looms. The typical weaving mill was, therefore, a small family business. Finishing (bleaching, dyeing, printing) also required fairly expensive machinery and as water rights were essential, the average finishing works was much larger in terms of capital employed than the average weaving mill.

The early 1900's saw the first stages of amalgamation and several large combines were formed in both spinning and finishing, while after the First World War several more large spinning combines came into being. The re-equipment subsidy after the Second World War was a further incentive for the smaller spinning units to join together. A survey carried out in 1952 showed the extent to which amalgamation had taken place. The 390 cotton and rayon spinning units in operation were controlled by 214 firms, 137 of which had less than 100,000 spindles each. However, five firms, each with more than 100,000 spindles, controlled about one-third of the total output of the spinning industry.

In weaving, the picture is quite different. The smaller concerns persisted, and are still to be found, but with the high cost of modernising buildings, and the cost of replacing Lancashire looms (non-automatic) by automatic looms there was a tendency towards grouping and verticality. Compared with the spinning section, 651 out of a total of 893 firms weaving cotton and rayon had less than 500 looms each, the most typical firm having only 100 looms; 25 firms each with over 2,000 looms account for over 21% of the industry's loom capacity.

This changing structure of the industry gave greater scope for the use of automatic machinery which by virtue of its higher costs encouraged shift working, but it must also be remembered that the textile industry has to cater for a vast number of consumers who demand quality goods at the lowest possible prices, and changes in world demand require flexibility of machinery. Furthermore, the nature of the raw material is such that yarn breaks occur during spinning and weaving. This sets a limit to the amount of automatic machinery that is economic.

The chief disadvantage of the present structure of the industry is that few manufacturers can look forward to many years production of a standard line. As many of the examples of automation described in this Paper are only suitable for bulk production, it will be appreciated why their introduction has been slow. The examples chosen represent the various aspects of automation, namely feedback control, automatic linking devices and advanced mechanisation.

SPINNING

In contrast to many other industries, the speed of spinning machinery is about the same or even slower than it was 50 years ago, but the labour force required to produce a given quantity of yarn has fallen by about 50%. This has been partially brought about by the introduction of high drafting and the use of large packages, and partially by a greater understanding of the principles involved in the drawing of fibres into uniformity and the mechanism by which twist is inserted. The strict control of every process has now become an absolute necessity.

The Raper Autoleveller

The first successful application of feedback control in spinning was patented by Raper in 1949, and is now being used on an ever increasing scale in worsted spinning. The autoleveller is a self-contained unit which can be used on any process where drafting takes place. Its function is to measure the thickness of the ingoing material and to regulate automatically the draft, thus correcting the variations as they are measured. In this way, a constant weight per unit length is delivered from the front of the machine.

Fig. 1 shows the action of the autoleveller diagrammatically. The material which may be in the form of loose slivers is fed into the machine through a condenser funnel A, thence to the measuring rollers B, which are located in line with, and in advance of, a pair of back rollers C. The measuring rollers B measure the cross-sectional area of the material passing through, automatically recording the variation in thickness as a pattern line in a relay mechanism. This relay mechanism retains the recorded patterns until the particular cross-section of material measured has reached a selected point in the drafting zone which is approximately half the mean fibre length behind the front roller nip. At this point, the pattern line is transferred to the transmitter unit which in turn controls a variable special mechanism, which makes the necessary correction to the draft by varying

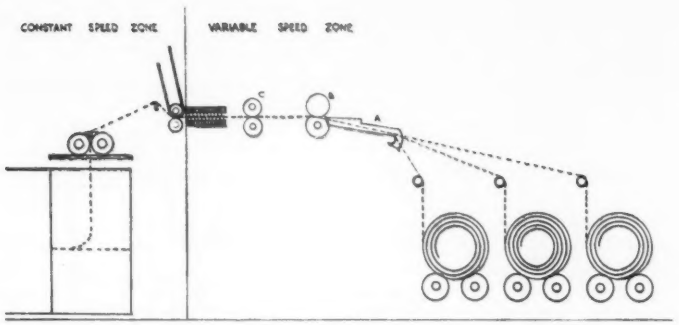


Fig. 1. Line diagram of the Raper Autoleveller.

the speed of the back rollers and associated members.

The unit is also fitted with other controls, such as an electrically operated detector which stops the machine in the event of a break within the drafting zone, and a graduated indicator showing the variation in the material as it enters the measuring rollers.

Mechanical Aids in Spinning

On many modern spinning frames (where the final drafting and twisting take place) overhead travelling blowers move along a rail fitted above the creel top and direct a stream of air downwards on to each side of the creel. The frequency with which the blowers pass any point on the frame prevents the accumulation of loose fibres, reduces the amount of cleaning necessary and improves the quality of the yarn. In a modern redeployed ring spinning room the percentage of the spinner's time spent on cleaning is approximately 50%. With the introduction of overhead blowers, this figure is reduced to below 40%. A further improvement is brought about by the use of pneumatic undercleaners and air conditioning, when this figure is reduced still further to as low as 10%.

WEAVING

Winding

After the yarn has been spun it has to be wound on to larger packages under controlled tensions to remove the weak places, and between pre-set clearer plates to remove thick places. It is perhaps in winding machinery that some of the most outstanding advances have been made in recent years. Machines have been designed with automatic transfer devices and with other mechanical aids so that a minimum of human effort is required.

One of the most successful machines for long runs of a given count (a measure of the fineness of the thread) is the Barber-Colman automatic spooler. This machine, shown in Fig. 3, consists of a long continuous drum on each side of the frame, each drum being driven by a separate motor. The yarn is wound on to packages formed on bakelite sleeves which fit over ball bearing cores and a travelling knotter automatically circuits the frame joining the old end of the yarn on the spool to the end of the yarn on the new tube.

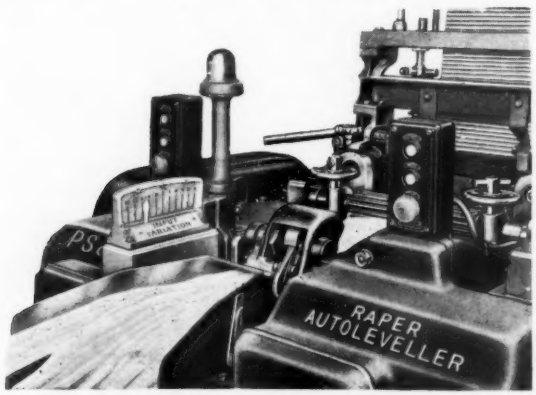


Fig. 2. Raper Autoleveller, showing the measuring head and indicator.
(Photograph by courtesy of Prince-Smith & Stells Ltd.)

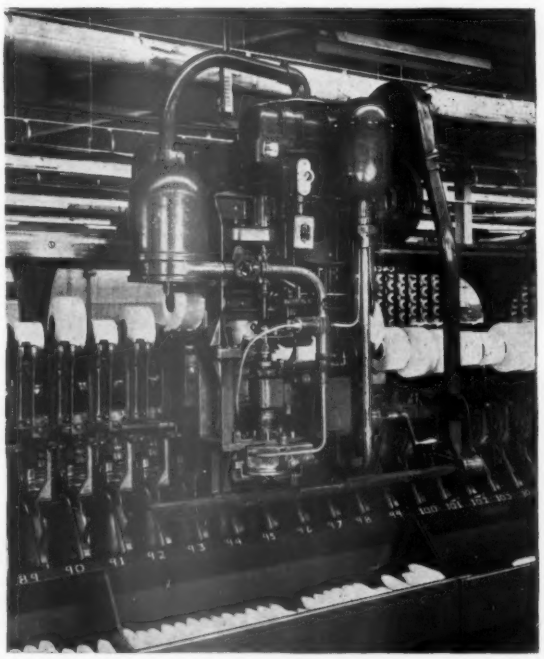


Fig. 3. Close-up of the Barber-Colman spooler, showing the automatic knotting head.
(Photograph by courtesy of Tootal, Limited.)

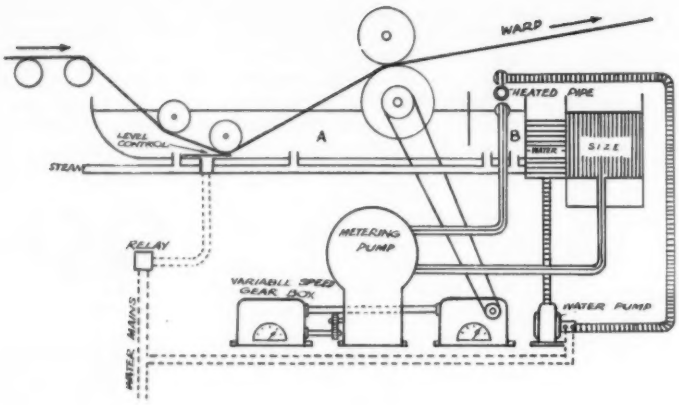


Fig. 4. Line diagram showing the action of the " Shirley " automatic size box.

When the traveller arrives at a spindle, it rejects the empty tube and replaces it with the one which has been placed in the pocket provided. It then stops the spool if it is still rotating, collects the free end from the surface of the package by vacuum and carries it to the automatic knotter, where the end of the new ring tube is already in position. The two ends are now automatically joined together with a weaver's knot, and the ends are trimmed. As the knotting unit moves forward, the package is rotated and is lowered on to the winding drum. The traveller is timed so that one complete circuit corresponds to the time taken for a ring tube to unwind completely. Arrangements are also made for detecting the full package, and for automatically lifting the package from the winding drum when the tube is empty or the yarn breaks.

The operative's duties as such are at an absolute minimum ; she follows the travelling head, fills the bobbin pocket on the machine and removes any full packages. These are placed on tridents which are carried on a small trolley which the operative pushes before her. Because of the nature of the knotting unit, it will be appreciated that the new bakelite sleeve which replaces the full package must always carry a small amount of yarn ; these tailings can be wound on a separate machine, but in the majority of cases, they are never completely unwound during subsequent winding operations. To give some idea of the production that can be expected from the Barber-Colman Spooler, the travelling knotter can knot at the rate of 90 knots per minute on a machine which may have as many as 306 spindles. Winding can take place at speeds up to 1,200 yards per minute.

SIZING

The " Shirley " Automatic Size Box

The object of sizing is to give each warp thread a coating of a suitable material which will enable the thread to withstand the various forces imposed on it during weaving. A number of beams are arranged in a creel, and all the ends combined to form a warp sheet. This sheet passes through the size mixture, between squeeze rollers and then either over heated cylinders or through a hot air chamber.

The " Shirley " automatic size box provides the means of obtaining and maintaining an accurate and predetermined percentage of size on the warp. The box automatically allows for variations in the viscosity of the mixing, the take-up characteristics of the warp, and the mechanical conditions imposed by the sizing machine. On the automatic box the operator can control his size percentage by setting two pointers on the variable speed gear box.

The basic principle behind the design of the box is that it delivers sizing ingredients at a rate at which they are required by the warp, and at the same time dilutes the size automatically by the condensation of the steam and by the controlled addition of water. This is carried out in such a way that the ingredients are used at the rate at which they are delivered.

The working of the box is shown diagrammatically in Fig. 4. The warp passes through a size box which is divided into a section A containing the working mixture and a section B where diluting of the concentrated size takes place. The level control detects any fall in the size level and brings the water supply into operation by closing the contact on the relay.

Assume that the box is filled to the required level with size of the correct concentration. If for some reason the percentage take up increases, resulting in an increase in the percentage of size on the warp, the level will drop and extra water will be added. If, on the other hand, the size take up drops, the amount of water normally added in a given time will be reduced. The viscosity of the mix will then increase until a point is reached at which more water will be required. The size percentage is, therefore, being continually corrected.

From this description, it will be seen that the Shirley Box does in effect use a type of feedback control. The interesting feature, however, is that it corrects all the factors which affect the size take up without measuring any of them.

The Shirley box is one of many automatic controls that can be fitted to existing machinery.

Tension and Moisture Control During Sizing

After the warp has been through the size box, it is dried by passing over heated cylinders or through a hot air chamber, and then wound on to a weaver's beam. The individual threads must have uniformity of strength, elasticity and cross section ; thus suitable headstocks have been designed which will not only wind at constant tension, but also at a controlled moisture content.

One of the best examples is the Patent Varispeed equipment developed by the Electric Construction Company, in conjunction with Joseph Hibbert Ltd., Darwen. Fig. 6 shows diagrammatically how these controls are effected ; the drive to the machine is obtained from two motors which drive the draw rollers (rollers which draw the warp sheet through the machine), and a beam motor which drives the weavers beam. Both of these motors are fed from the mains A.C. supply through a transformer, which provides the various voltages required on the equipment, through an induction regulator, which by varying the armature voltage of the two motors gives complete coverage over the linear speed range of the machine, and finally through a Mercury Arc rectifier which converts the A.C. power into D.C., the latter being the type most suited to a drive where a wide speed range is required.

It will be appreciated that as the diameter of build-up on the weaver's beam increases, the drive must be slowed down in order to give the same linear peripheral speed, but at the same time the torque applied to the beam drive must increase. This is achieved by means of a shunt-controlled speed range on the beam motor. This range covers all beams having a 6 : 1 ratio of build-up from bare barrel diameter to flange diameter. During the beam build-up, its speed is continuously reduced and the tension on the yarn is kept constant by means of the tension control unit which measures continuously the power input to the beam motor, and corrects any deviation from the set tension by adjusting the beam motor field regulator which is automatically driven by a small pilot motor.

The alterations to the field regulator affect the beam motor field conditions so as to give the correct peripheral speed on the beam at all times, and at the same time adjust the torque to that required in order to give the correct tension on the yarn.

The second factor which is automatically controlled on the machine is the moisture content of the yarn.

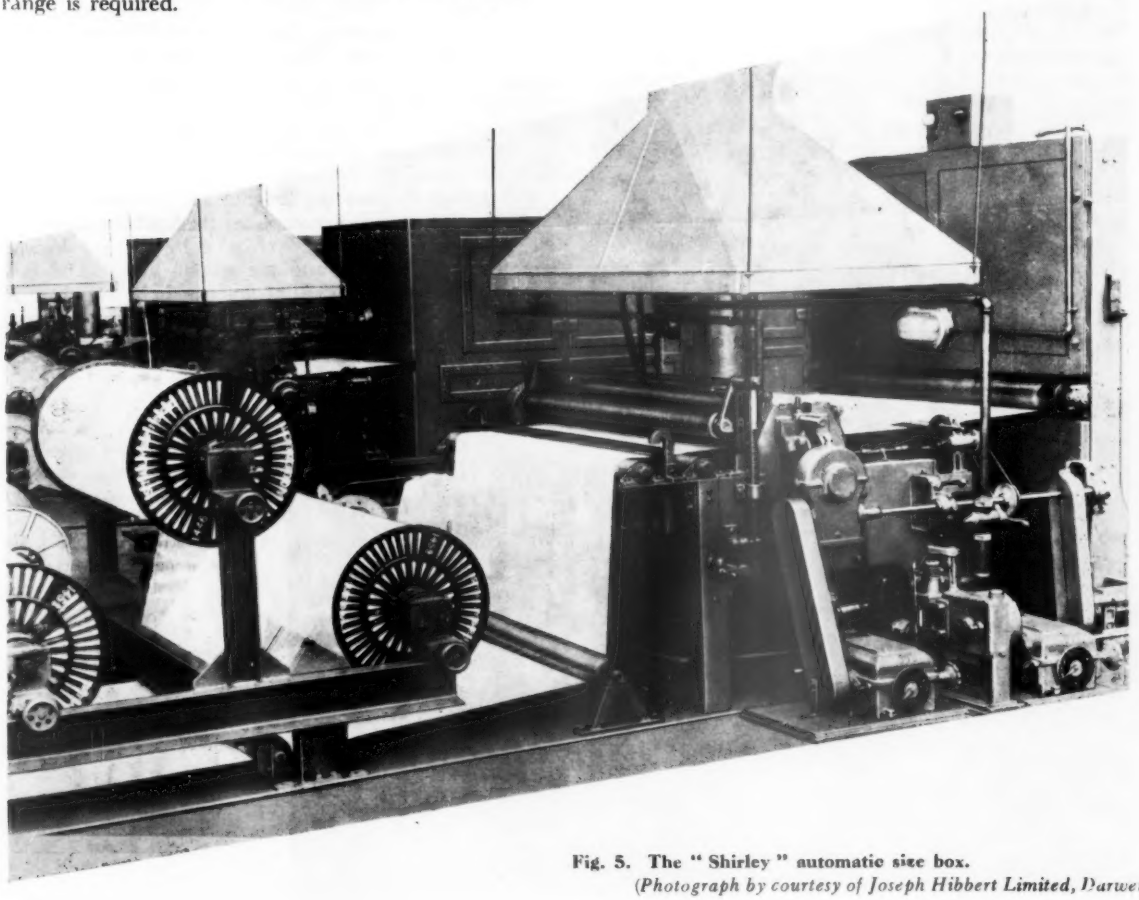


Fig. 5. The " Shirley " automatic size box.
(Photograph by courtesy of Joseph Hibbert Limited, Darwen.)

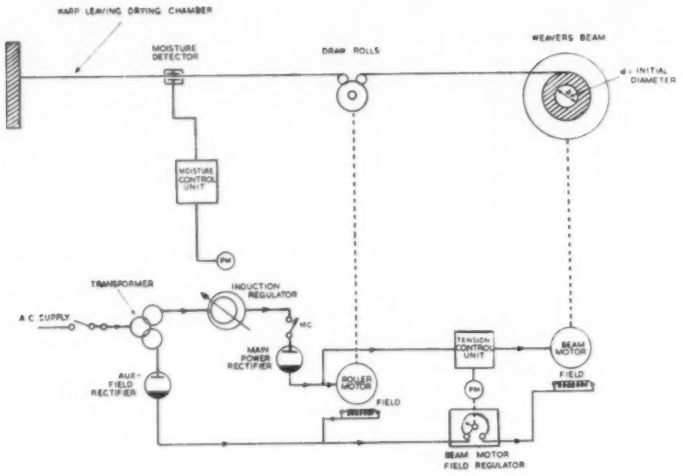


Fig. 6. Line diagram of the E.C.C. Varispeed Drive.

(Diagram by courtesy of the Electric Construction Co. Ltd., Warrington.)

As shown on the diagram, an electronic moisture control unit is used in conjunction with the drive to regulate automatically the speed of the yarn leaving the drying chamber in accordance with any moisture changes detected by the moisture detector unit. For instance, should the yarn leaving the drying chamber be too wet, the moisture control unit will initiate movement of the induction regulator through its small driving motor, and this movement will slow down the speed of the two driving motors. Conversely, should the yarn leaving the drying chamber be too dry, the speed of the yarn will be increased through the drying chamber in order to reduce the drying time.

Tension and moisture content are, therefore, automatically measured and corrected continuously, and help to eliminate the effects of the human element in producing consecutive beams of consistent characteristics.

Pirn Winding

Modern pirn winding equipment demonstrates both advanced mechanisation and examples of automatic transfer devices. As one pirn is filled, another is automatically transferred to the spindle, and winding continues.

Fig. 8 shows a section of a Schweiter fully automatic pirn winding frame. The empty pirns are tipped into a revolving hopper in which they are selected and allowed to fall to the base of a vertical conveyor. The pirns are then fed into a circular battery from which they are dropped into pockets on a moving belt which travels round the frame.

Consider the winding cycle of an individual spindle unit ; as winding is complete, the spindles cease to rotate and the full pirn is released by the withdrawal of the spindle head into the spindle box. The full pirn falls on to a small conveyor belt where it is

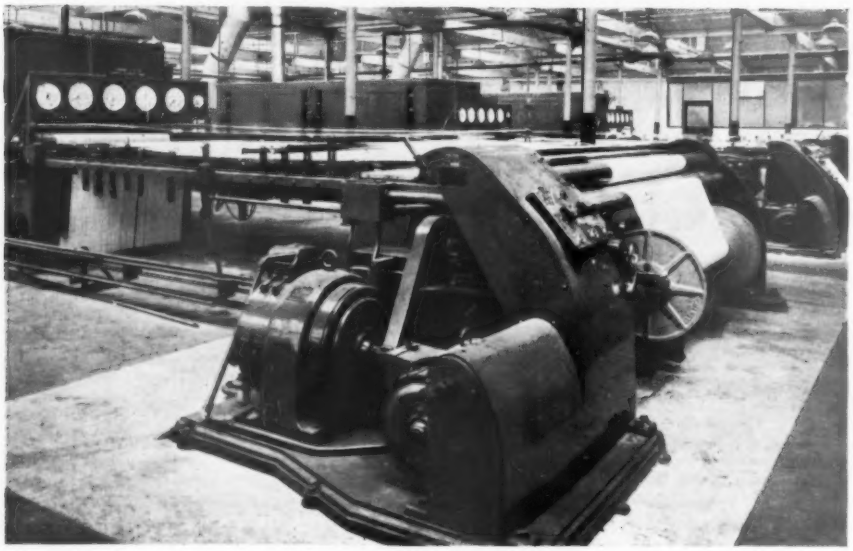


Fig. 7. The E.C.C. Varispeed drive fitted to a Hibbert hot air sizing frame.

(Photograph by courtesy of Joseph Hibbert Limited, Darwen.)

carried to the end of the frame for packing. Meanwhile, the new pirn which has been lying on a horizontal arm is carried forward and held in position as the spindle head moves forward out of the spindle box. As soon as it is firmly gripped, the carrier arm moves back and the spindle starts to rotate. During the change cycle, the yarn remains threaded through the guides and is placed between the pirn butt and the spindle head.

The carrier arm is now reloaded with a new pirn by a "finger" which opens one of the pockets on the conveyor belt which encircles the frame.

The mechanism is also fitted with cutters for separating one pirn from the next, and with automatic stop motions. Further refinements also include an automatic packing unit and an automatic cleaning device. These are shown in Fig. 9.

Weaving

The automatic loom was an early example of automatic transfer which was slow in being accepted in the industry. The essential element which distinguishes these looms from ordinary looms is that the weft is replenished automatically from a reserve supply, conveniently held in readiness. There are, of course, many other auxiliary attachments which are incidental to the weft replenishing devices, and which increase their efficiency. The first Patent Specification for automatic weft replenishing is dated March, 1834, but the one which is better known was filed in October, 1840, by Parker. Between 1834 and 1894 a total of 32 patents were filed for automatic weft replenishing devices. Perhaps the most successful was the one patented by James H. Northrop in Hopedale, U.S.A.

The essential features of the Northrop invention which distinguishes it from all others is that the weft pirns are retained in a circular rotary magazine and inserted into a self-threading shuttle by a simple hammer action.

At the opposite side of the loom to the magazine, a feeler passes through a suitable slot in the front wall of the shuttle, and engages against the pirn as the sley moves forward. If there is still weft present, the feeler is depressed. When the pirn is nearly empty, the feeler touches the wooden barrel and is displaced sideways. As the sley moves forward, and the shuttle is fully boxed under the magazine, the transfer hammer pushes the empty bobbin out through the bottom of the shuttle, and replaces it by a new one.

Fig. 8. Close-up of the Schweiter automatic pirn feeding device, showing the path of the pirn from the revolving hopper to the spindle.

(Photograph by courtesy of Tootal, Limited.)

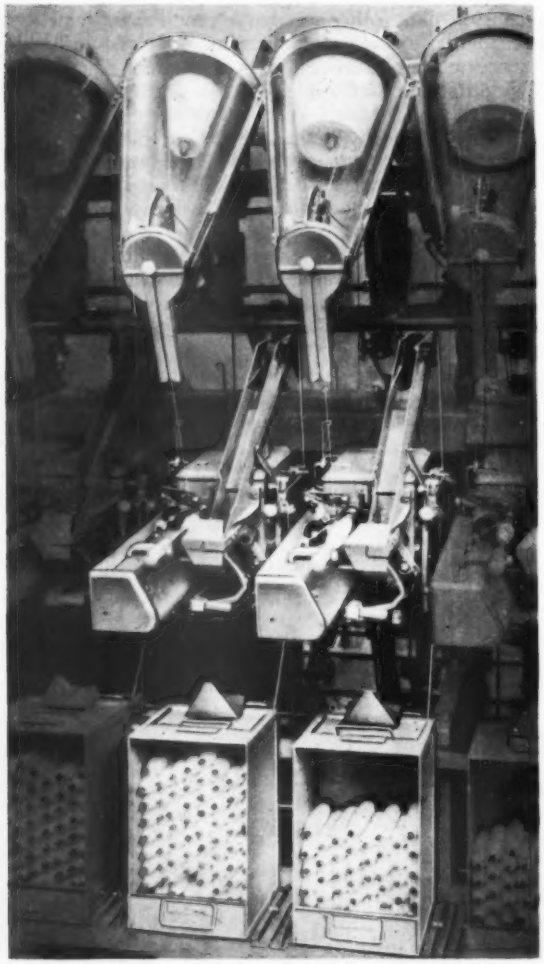


Fig. 9 *(left).* **A section of the Schweiter fully automatic pirn winding frame with automatic packing and automatic cleaning.**

(Photograph by courtesy of Schweiter Ltd., and Livesey & Aspinall Limited.)

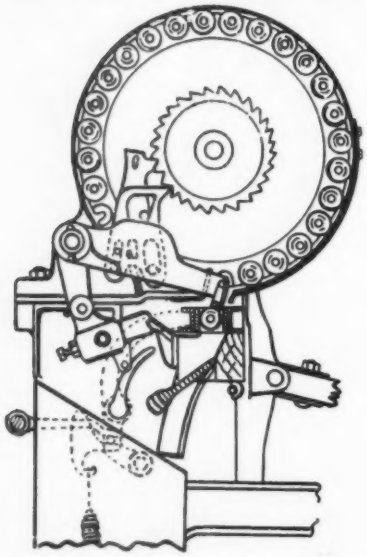
The end of the weft on the new pirn is attached to a part provided on the magazine, and the design of the shuttle eye is such that it is self threading.

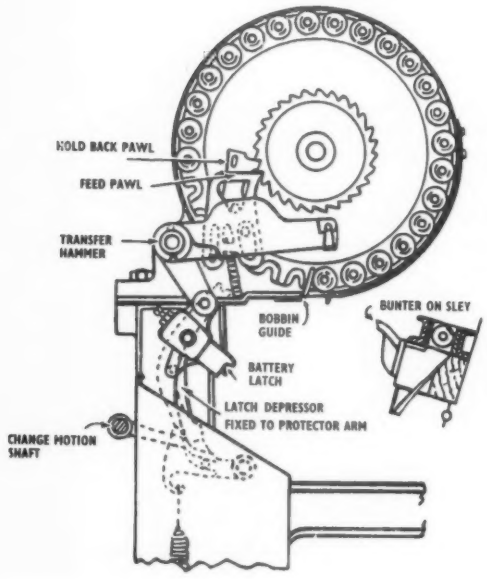
Automatic Shuttle Changing Looms

This again illustrates a method of automatically replenishing the weft without human aid. A stationary vertical magazine is fitted to the loom at the opposite end to the weft feeler. When a shuttle change is required, the loom is stopped by the action of the weft feeler, with the shuttle at the magazine end, and with the crank shaft at its furthermost position from the front of the loom. A cam shaft is set in operation which lifts the shuttle box front, pushes the old shuttle out of the box, lowers the new shuttle on to a conveyor which places it in the box, and then replaces the shuttle box front. The loom is automatically restarted. The complete change takes between three and four seconds and is a more gentle action than the bobbin or pirn change mechanism. It is, therefore, widely used for the more delicate types of weft. Other shuttle changing looms have been developed where the shuttle is changed without the loom stopping.

Fig. 10 *(below).* **The Northrop automatic pirn transfer device, showing the machine in the operative and non-operative position.**

(Drawing by courtesy of British Northrop Loom Co. Limited, Blackburn.)





The Sulzer Loom

The Sulzer loom employs a method of weft insertion whereby small pirnless weft carriers fitted with a weft gripper draw the yarn from large cross wound cones. These weft carriers are only 3½" long and weigh 1½ ozs. Weft insertion takes place from one side of the loom only, and during its passage through the interlaced warp sheet, the weft carrier runs in a steel guide, thus providing positive control. A conveyor underneath the sley returns the weft carrier to the picking side of the loom for re-use. As the loom uses a number of these carriers they are returned at a moderate speed although the rate of weaving is high.

After insertion, the weft is cut and tucked to form selvedges.

The Sulzer loom is mentioned in this Paper because it represents a new approach to weaving as distinct from the application of further advanced mechanisation to existing machinery.

Another interesting difference is that the weft supply is continuous in that the end of one cone can be attached to the beginning of another. The need for pirn winding is, of course, eliminated.

Other Aspects of Automatic Weaving

Labour specialisation is far more essential in automatic weaving than is normally found on non-automatic looms. The duties of the weaver, who is a highly skilled operative, are reduced to the absolute minimum, in many cases to repairing warp and weft breakages only. This enables the weaver to supervise the maximum number of looms. Battery filling, cloth carrying, sweeping and oiling can be carried out by less skilled labour. Redeployment schemes on automatic looms have been carried out in the industry, but more could have been done in view of the restricted labour force available. The following table illustrates the slow progress that has been made in the introduction of automatic looms.

Cotton Board Surveys

Date	Total No. of looms	Non-automatic	Non-automatic with automatic attachments	Automatic
1949	406,280	377,650	2,911	25,719
31.7.53	364,763	317,809	5,364	41,590

Of the 406,280 looms in 1949, only 37,497 were fitted with individual drives.

It has often been said that whatever the gains to be derived from the production of certain cloths on automatic machinery, some traditional Lancashire equipment must be retained. On the other hand, from a national point of view, it would seem that the fewer the operatives required to produce a given length of cloth, the more labour will be available for other industries. The Cotton Textile Mission to America in 1944 gave figures of the number of looms per operative employed in American mills (where a high degree of standardisation has taken place, and where mills are fully equipped with automatic machinery) and for similar cloth woven on traditional equipment in Lancashire.

Comparative Looms per Operative

	Coarse cloth	Medium cloth	Fine cloth
U.S.A. ...	6.3	13.2	11.8
Lancashire ...	3.03	4.46	4.6

Many of the new mills in Lancashire can produce figures similar to those obtained in the U.S.A. Unfortunately these mills only account for a small percentage of the country's output.

Process Control

Increasing competition in the textile markets is forcing manufacturers to increase their quality as well as to lower their costs. With the introduction of modern labour saving machinery, it is inevitable that there should be a demand for measuring instruments for checking quality at various stages of production. Two of the more essential properties of a yarn which are conveniently measured are the evenness and the breaking load. Both of these properties have been the subject of many years research by Zellweger Limited in Switzerland. Their evenness tester, which is electronic, records the varying cross-sections of the sample, and analyses the results for any periodic faults that might be present.

However, as far as automation is concerned, there has been an interesting application of automatic transfer to the testing of yarn strength. The automatic yarn strength tester selects its own sample from a suitable package, and performs the single thread test automatically with a constant rate of loading. At the same time, the machine records the cumulative totals of breaking load and elongation and supplies a frequency distribution of breaking load.

The automatic multiple bobbin attachment permits the continuous testing of from one to ten individual bobbins in test groups of either 5, 10, 20 or 40 tests per bobbin. Once the device has been set-up and put into operation, it automatically changes in sequence to the next bobbin after the desired number of tests and continues until all the specified bobbins have been tested.

FINISHING

Bleaching, Dyeing, Printing, Crease-Resisting

The problems facing the cloth finishers are perhaps more insurmountable than those of any other section of the industry. Because of the horizontal nature of the industry, the average finisher must be prepared to deal with a wide range of fabrics from a wide range of manufacturers. Unfortunately each manufacturer has his own ideas on sizing ingredients, and other variables which have to be overcome in finishing. This at once imposes a severe limitation to continuous processing with all its automatic controls, because it is virtually impossible to standardise a treatment which will give the same degree of whiteness after bleaching or a certain depth of shade after dyeing. The other limitation is that with the improving standard of living throughout the world, protection against the elements is no longer the prime function of clothing. Fabrics are now being judged by aesthetic appeal — a subjective judgment which leads to changes in fashion.

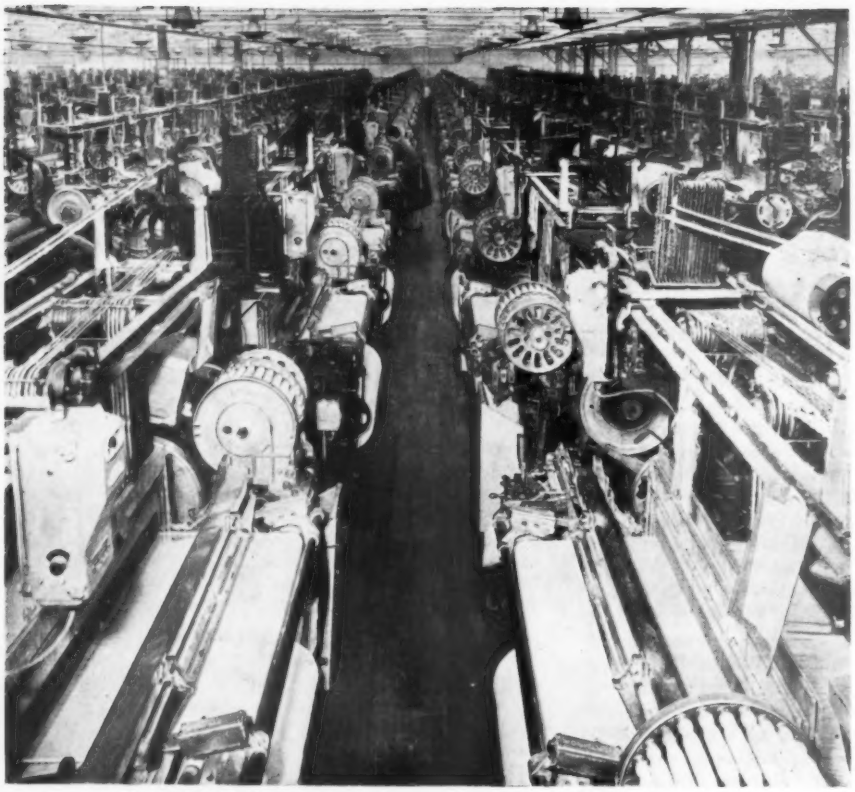


Fig. 11 *(top).* **A modern weaving shed at Sunnyside Weaving Limited, St. Helens, using Northrop automatic looms.**

(Photograph by courtesy of Tootal, Limited.)

Fig. 12 *(left).* **The Uster Automatic Yarn Strength Tester.**

(Photograph by courtesy of G. W. Thornton, Limited.)

Despite these limitations, there are many continuous processing units in use. Only certain samples that illustrate interesting methods of control will be discussed in this Paper.

Continuous Processing

Continuous processing means the coupling together of certain processes so that the long runs of cloth can be fed into a multi-stage machine. However, most textile materials are dimensionally unstable in the early stages of finishing, and compensators have to be used to allow for length changes that may take place at each stage of the process. A compensator is a single horizontal roller mounted so that its movement in a vertical direction can be used to vary the speed of the unit process it controls.

The compensator may be used in conjunction with one of three control units.

Dancing Roller Control

Movement of the compensator is made to operate a limit switch. This switch comprises an inner rotatable and an outer rotatable member. The inner member is controlled by the movement of the dancing roller. As this roller moves vertically in either direction, the inner member rotates until its contacts touch similar contacts on the stationary outer member. This energises the pilot motor which, through the brush gear on a variable speed motor, moves the brushes through an arc. The brush gear is connected mechanically to the outer member of the switch so that when the brush gear moves, the outer member of the limit switch moves.

This method of control is robust, but only operates outside distinct limits.

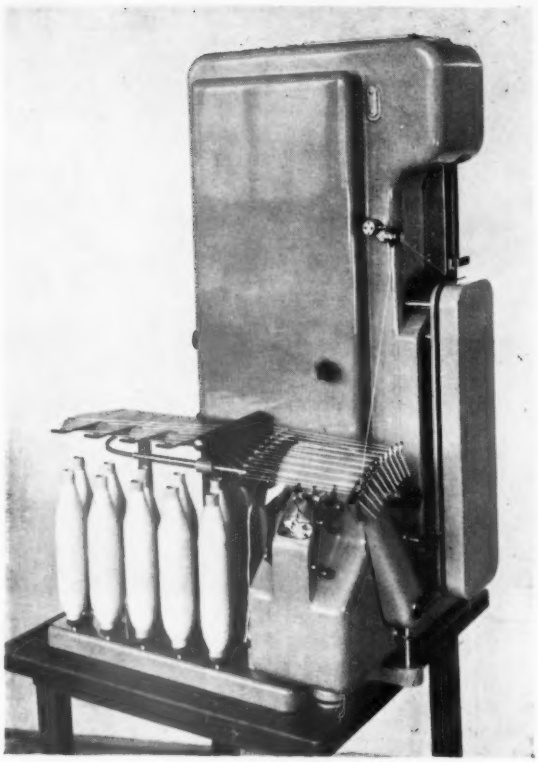


Fig. 13. Rear view of the Uster Automatic Yarn Strength Tester, showing the multiple bobbin attachment.

(Photograph by courtesy of G. W. Thornton, Limited.)

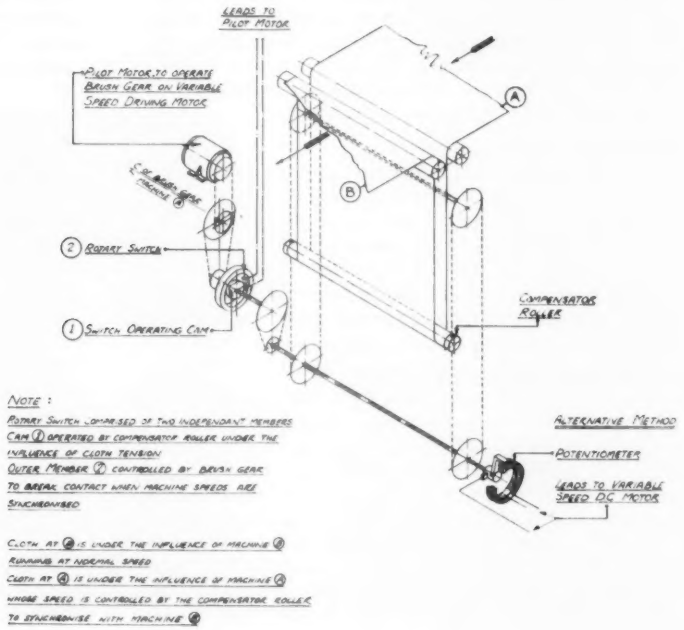

LEADS TO PILOT MOTOR
PILOT MOTOR TO OPERATE BRUSH GEAR ON VARIABLE SPEED DRIVING MOTOR
A
B
② ROTARY SWITCH
① SWITCH OPERATING CAM
COMPENSATOR ROLLER
NOTE :
ROTARY SWITCH COMPRISED OF TWO INDEPENDANT MEMBERS
CAM ① OPERATED BY COMPENSATOR ROLLER UNDER THE INFLUENCE OF CLOTH TENSION
OUTER MEMBER ② CONTROLLED BY BRUSH GEAR TO BREAK CONTACT WHEN MACHINE SPEEDS ARE SYNCHRONISED
CLOTH AT ③ IS UNDER THE INFLUENCE OF MACHINE ③ RUNNING AT NORMAL SPEED
CLOTH AT ④ IS UNDER THE INFLUENCE OF MACHINE ④ WHOSE SPEED IS CONTROLLED BY THE COMPENSATOR ROLLER TO SYNCHRONISE WITH MACHINE ③
ALTERNATIVE METHOD
POTENTIOMETER
LEADS TO VARIABLE SPEED D.C. MOTOR

Fig. 14. A single roller compensator, showing diagrammatically how it operates either *(a)* rotary switch, or *(b)* potentiometer.

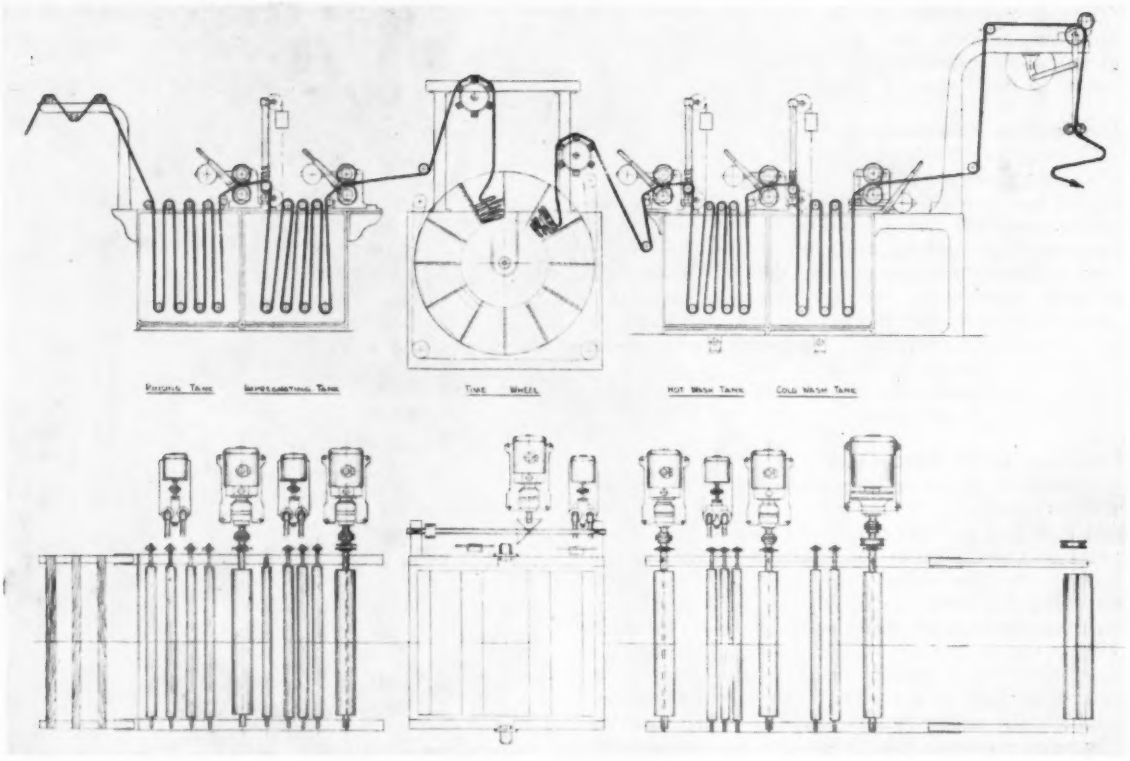


Fig. 15. Diagram of the Farmer-Norton open-width scouring range, showing three compensators and a time wheel.

(Drawing by courtesy of Sir James Farmer Norton, Limited.)

Ward Leonard Control

The overall speed control is obtained by connecting all the motors with their armature in parallel, and controlled by a variable voltage generator. The trimming between the separate motors is obtained by shunt field control using the compensator.

Electronic Control

If high speeds and accurate tension control are essential, the high speed of response of thermionic values has to be used. One motor is chosen as the master to which all other motor speeds are related. Any deviation in tension is again reflected in the vertical movement of the compensator which controls the setting of a potentiometer and trims the speed of the driving motor.

Control of Processing Time

This can be obtained by varying the length of the machine or by the use of time wheels. On a large multiple machine, both these controls may be used. Fig. 15 shows diagrammatically an open width scouring range designed by Sir James Farmer Norton Limited, and installed at the Tootal finishing works. The cloth enters the first unit where hot rinsing takes place and after passing over a compensator and through the impregnating tank is plaited into the time wheel. The cloth may remain in this time wheel for a length of time depending on its size and design. Two more compensators are fitted to the two final units. The cold wash, which is only a short time treatment, has three passes through the liquid and not four as on the other units. The principle of coupling units as described is not restricted to open width scouring.

Other Automatic Controls

Cloth is normally dried on a stenter, which is a machine designed to hold the cloth at a predetermined width, while hot air is directed on to its surface. The cloth moves forward at a speed dependent on the rate of drying of the material in the stenter.

The modern development of the pin stenter brought with it a need for accurate guiding of cloth selvedges. Hand-feeding for pin stenters required considerable skill and, where the finished cloth was to have the minimum of shrinkage, a considerable amount of overfeed on to the pins was often necessary. Even the most skilful of the hand feeders were unable to do this with any degree of accuracy, and as the speed of stenters gradually increased, the need for an automatic selvedge guide became imperative.

The Pneumatic Selvedge Guide

With this attachment, which can be fitted to a conventional stenter, the cloth selvedges are brought

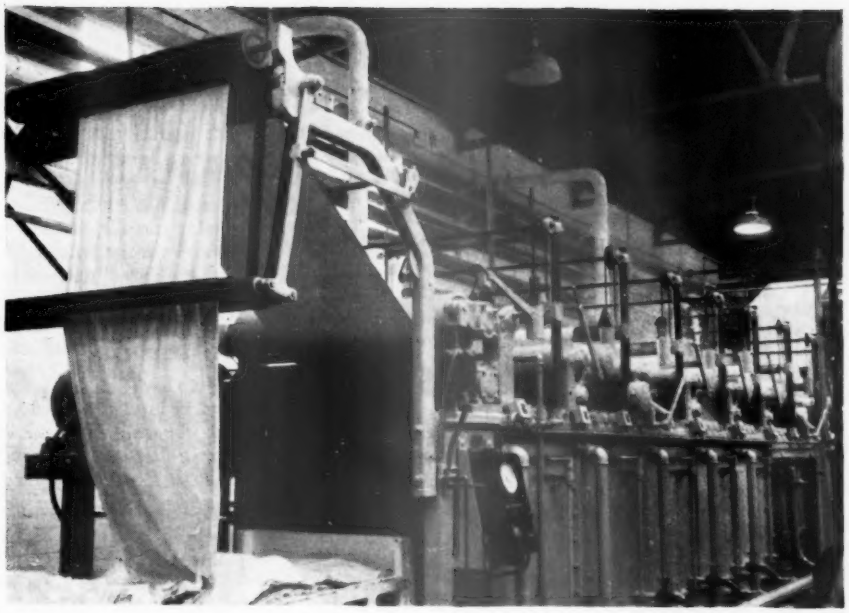


Fig. 16. Cloth leaving a continuous dyeing machine. This machine has seven compensators.

(Photograph by courtesy of Tootal, Limited.)

into contact with feelers which operate valves which control the admission of air into the guiding apparatus. Thus the guiders follow closely changes in cloth width and ensure that the pins take hold of the selvedges only. The guider comprises a fairly large diameter double acting air cylinder attached to each guide rail. Compressed air is admitted to both sides of the piston so that it is in a state of equilibrium. Movement of the selvedge feeler causes a light vane to open one or two air jets directed towards the ends of pipes. This builds up pressure in a diaphragm valve which opens and exhausts air from one end of the cylinder, causing the rail to move. The jet is cut off again when the normal position of the selvedge feeler is reached, and the balanced pressure is restored in the cylinder by means of a slow flow of air past a restricted needle valve.

Photo-electric Selvedge Guide

For higher stenter speeds, the response time of a pneumatic selvedge guide is too slow and the photo-electric guide was developed.

The cloth selvedge is fed under tension between the light source and the mirror of the photo-electric selvedge detector, over the guider wheel and thence, *via* the overfeed wheel, on to the pin chain of the stenter or *via* the transfer wheel into the clips of the clip stenter. The lateral position of the selvedge determines the amount of light reaching the cell

(concluded on page 240)

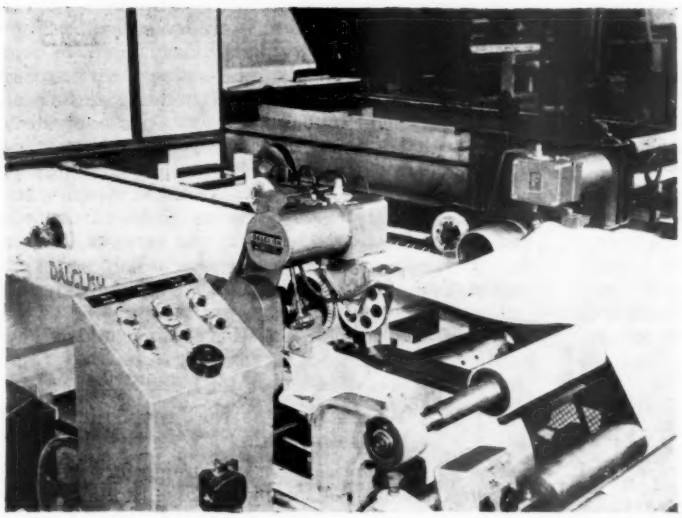


Fig. 17. The electronic selvedge guide and overfeed fitted to a pin stenter. The push button control can be seen at the left-hand side.

(Photograph by courtesy of John Dalglish & Sons Ltd.)

WORK DESIGN AND TRAINING FOR FUTURE INDUSTRIAL SKILLS

by N. H. MACKWORTH, M.B.Ch.B., Ph.D.

Presented to the Institution in London, 9th February, 1956.

Dr. Mackworth

Dr. Mackworth graduated in medicine at Aberdeen University in 1939 and came to Cambridge to work for the Medical Research Council under the direction of Professor Bartlett in 1940. Later, in 1944, the Medical Research Council established their Applied Psychology Research Unit at Cambridge to study problems relating to the performance of people working under difficult conditions.

In 1947 Dr. Mackworth was elected to a Research Fellowship at St. John's College, Cambridge, and in the same year he obtained the degree of Doctor of Philosophy at Cambridge University for work entitled "Researches on the Measurement of Human Performance". Then, in 1954, he was appointed Director of the Medical Research Council Applied Psychology Research Unit.

SIR Walter Puckey* pointed out in his opening address as President of this Institution at the Margate Conference in 1955, that the introduction of automatic processes may make us encourage skill because we shall demand so much more of it. He said that it seems inevitable that relatively more people should work at tasks such as designing, controlling and maintaining machines, and that this skill should be provided from existing people who will improve their status and earnings accordingly.

I have, therefore, taken the theme of the encouragement of future industrial skill as the guiding idea for this talk, because it seems important to consider the possible ways in which scientific research on people could help in this matter. Let me say right away that I believe that applied experimental psychology could make a real contribution — but let me add at once that this cannot initially be a matter of providing completely ready-made solutions. I do suggest, however, that applied psychology has now and today a number of methods based on practical experiments which could help in the study of industrial problems. With suitable changes, these methods should therefore be used on a wider scale than they are at present.

To be specific, I have chosen for discussion two of the possible approaches — (1) *work design*, and (2) *training*. Even so, these are both very wide ranging topics and I have, therefore, still further narrowed the scope of the Paper itself by choosing problems from only two areas of industrial activity.

Part 1 deals with *Work design for inspection and decision taking* ; Part 2 considers some matters related to the *Training of electrical maintenance workers.*

In general, this Paper is largely a discussion of two areas which I imagine are likely to be fruitful for a practical research programme. Problems have been considered which might also have some further implications for a better understanding of certain general aspects of human behaviour. No one will be more pleased than myself, however, if comment on this Paper raised and defined some quite different questions which could be tackled by experimental techniques of this kind. It would be particularly interesting if we found that it was generally agreed that these other problems are going to be even more important for industry in five to ten years from now.

Alternatively, I hope that you will point to vital questions which should have been raised under these headings of Part 1 and Part 2.

Part 1. Work Design for Inspection and Decision Taking

The aims of work design are straightforward — to arrange the work that people are asked to do in such

* References with an asterisk are taken from "*The Automatic Factory — What does it mean ?*" Report of the Institution of Production Engineers Conference at Margate, 1955.

a way that they have a task which is well suited to human ability. Not only will the work be done more effectively, but the worker will benefit because he will find the work easier ; being less tired, he runs less chance of an accident.

So obvious and simple are the objectives that such ideas are often completely overlooked. Every day many cars are built out of which it is impossible to get a good view of the road, either by looking forward or into the driving mirror (Grime, 1954). No very exact or scientifically elaborate measurements need be taken to find the faults in such arrangements; indeed, I believe that a great deal more could be done by applying ordinary commonsense to such problems. (McFarland et al, 1953; McFarland, Dunlap et al, 1953; McFarland and Moseley, 1954.)

The commonsense approach, however, will usually break down with complex problems, or with those involving entirely new forms of work, and this brings in the need for exact measurement. The results are sometimes very revealing when specially devised measures of human achievement are used with some standardised form of the task. A friend, who is both an experimental psychologist and a mechanical engineer, recently mentioned that a prototype device he had been testing in this way had now reached the satisfactory stage that all that the designer had to do was to specify and produce an entirely new type of human being to work the machine.

This Paper is, however, more concerned with the operator's task at his place of work — rather than with the equally important questions related to the tasks set by the products of the factory.

(a) Work Design for Inspection

The 1955 Margate Conference proceedings suggest that the industrial tasks of the future will lead to a temporary increase in the importance of inspection work. Lord Halsbury* has mentioned that on the whole it has been more difficult to devise control and communication engineering procedures which will take over the functions of brain and nerves, than it has been to work out transfer machines to replace muscle power. Sargrove and Huggins* believe that the superimposition of human inspectors on automatic plants is only transitionally justified as this will eventually become an anachronism. They claim that automatic inspection is the key to successful, long-term automation. Peacock* also goes so far as to say that the most important rôle for electronics in the automatic factory will be in automatic inspection. Remarkably ingenious devices are now being developed and tried for automatic inspection purposes — and a number are already in use — but it does seem clear that there may well be an interim stage during which these devices are under development before they can be introduced to take over a large number of tasks. For a time, machine production is going to create a huge number of products for human inspection. We seem to be some way yet from full automation with its perfect harnessing of electronic brains to mechanical muscles.

How does the human being fare at inspection work ? In trying to answer this question with experimental evidence, instances have been taken from four kinds of inspection work. These might be regarded as typical of some of the tasks found when the circumstances range from no automation to fully automatic processes. (Space permits only a brief account of these studies — see the original references for details.)

(1) *Continuous inspection for misalignments*

The work of the inspector is being measured when he is continuously regulating a process changing in one dimension only.

(2) *Consecutive inspection for misalignments*

Here measurements are taken when the inspector is accurately and quickly making a series of consecutive settings on a machine.

(3) *Consecutive inspection for sporadic defects*

Now the inspector has to detect single items which occur infrequently and are slightly different from a whole series of standard objects.

(4) *Monitoring automatic machines for emergencies*

This considers the supervision of automatic machines to forestall breakdowns and to minimise the down-time of the machines.

(1) *Continuous inspection for misalignments*

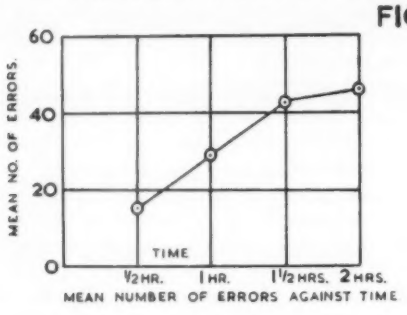
Peacock* points out that it is very usual for an operator to observe the reading of an indicator and to adjust his controls to maintain its value constant. The operator is an essential link in the process and himself receives the signal and uses his powers of judgment to adjust his controls suitably. The control loop of the process is thus closed by means of the operator. (In a fully automatic process this would be closed by a suitably electronic feedback system, with many attendant advantages. Such systems are found in the automatic pilot and in the chemical and petroleum refining industries.)

Some important work related to human performance in a continuous regulation task has recently been done by Siddall and Anderson (1955). They tested 21 people on a simple form of work in which the operator had to prevent a mark from moving away from a given setting by turning a hand-wheel at a fixed speed. The men working at the task were all keen, and found no difficulty in producing error-free runs, provided these lasted for only 10 minutes or so. But two-hour runs gave a very different picture. Figs. 1 and 2 show that the average amount of errors and also their duration rose steeply during the period of work. There were large differences in ability at this work, but the best men at the start of the spell were also the best in the last half-hour.

Siddall and Anderson interpret these changes as being due to the markedly continuous nature of the work. It is known that the relative absence of change in the sensory input has harmful effects on human achievement. Here, for example, it is possible that one such effect was the appearance of short gaps in visual perception, so that the operator became less alert from time to time with the result that his accurate regulation of the control occasionally failed for a moment or two. The authors are, however, less convincing in their attempt to argue against the other possibility that part at least of this performance

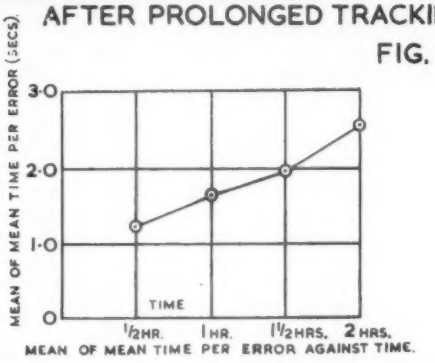
ERRORS DURING PROLONGED AND CONTINUOUS TRACKING

FIG. 1.



SLOWER ERROR CORRECTION AFTER PROLONGED TRACKING

FIG. 2.

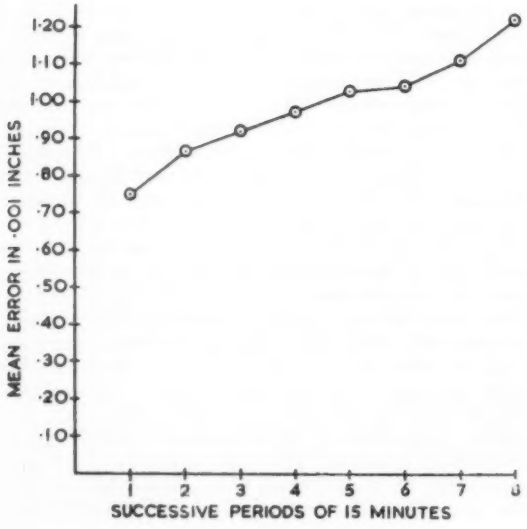


decrement was due to an increasing muscular fatigue. (This point will be taken up in the following section.)

It is undeniable that work of this kind can often be done more successfully by entirely automatic sensing devices ; a good example is given in the Sargrove and Huggins* Paper, to illustrate how even rapid changes in the thickness of extruded polythene cable could be automatically controlled to within about ±0.002" by an electronic micrometer deviation measuring head. There is the other side of the picture, however. Just as the experimental psychologist should draw attention to jobs that are really better tackled by machines — so it would be useful if the engineer could indicate at an early stage in development any specially difficult inspection tasks which humans have to undertake because no machines can yet be devised to do the work.

PROGRESSIVE INCREASE IN ERROR DURING REPEATED VERNIER SETTINGS

FIG. 3.



(2) ***Consecutive inspection for misalignments***

Siddall and Anderson (1955) may well be right in emphasising the possibility that an explanation of their results is more likely to be related to difficulties with the human input side, i.e., when their work is taken together with some recent unpublished work by Saldanha (1955). The evidence here is that similar changes do occur during a two-hour period in which people were doing an exacting visual task which had the minimum of muscular effort. The 18 men investigated were setting a Vernier calliper gauge by a handwheel to the nearest one-thousandth of an inch, a whole series of readings being provided. Accuracy and speed were stressed as requirements at the start of the test.

Fig. 3 shows the average progressive deterioration in accuracy during the two-hour test — an error increase of 64% from start to finish. During the first hour there was little change in the speed of work, but this rose slightly in the second hour so that the men were now working 11% faster. Again there were marked differences in ability at the task itself, despite the fact that all the subjects (who were either engineering students or sailors) had to reach an average accuracy of not more than ±0.0005" before being tested.

It is interesting that accuracy can fall off in the Vernier setting because it is hardly conceivable that muscular fatigue could have caused the decrement here. The small light handwheel was moved to a new setting only once every 20 seconds or so. Secondly, it is interesting that this decrement was found despite the fact that the task provided by Saldanha was not continuous; the next signal in the series was not dependent on the previous response. Siddall and Anderson (1955) have made the suggestion that the term consecutive task might usefully be applied to such forms of work which involve a series of independent signals. Here the operator has slightly more changes in his environment per unit of time than he has in the continuous task. Thirdly, Saldanha has shown that decrement can occur to a marked extent in a consecutive task even when the operator is himself setting the pace. Broadbent (1953a, b and c) has shown that these self-paced jobs are less likely to lead to effects which are due to these momentary lapses of attention, simply because slack

moments can quite unconsciously be arranged in the work to coincide with such gaps in effective visual perception.

Other research by Conrad (1955a and b) and by Mackworth and Mackworth (1956a) has shown, however, that it is of real importance from a production point of view, apart from the question of fatigue, to avoid the rigid time spacing of successive events created by a conveyor belt. When the inspector has no store of articles waiting to be inspected he must take exactly the same time on each object. This is an impossible requirement for a human being, as everyone will vary the time taken with each successive item. On the other hand, an equally difficult situation is produced if a number of belts or machines has to be dealt with at the same time, for such a situation is liable to require bursts of high speed activity too fast for the operator, followed by quiescent periods during which he is not required to do anything. If the machine speed is kept down to a level at which the maximum speed can be followed, then much time is wasted. Conrad (1955a) found an instance in which inspectors were working at half their possible speed because they were tied to this unvarying pattern of one item at a time, each object arriving after a given number of seconds; they were not provided with a waiting store of objects from which they could draw their material.

(3) *Consecutive inspection to detect sporadic defects*

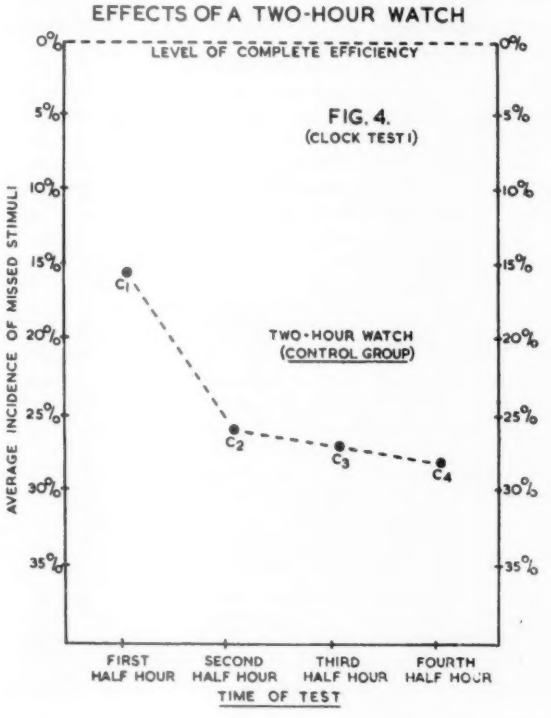
The case for the introduction of fully automatic inspection is strong, but for some years yet, highly skilled inspectors will be "ceaselessly engaged in inspecting tens of thousands of good products and searching, with difficulty, for the few defective products which occur from time to time and contaminate the product". Sargrove and Huggins* also rightly emphasise "the fallibility of human inspectors under the hypnotic effects of endless repetitive examinations of a mass-produced article, the bulk of which is correct anyway". The importance of any change in the standard of work accepted by human inspection is, however, very great, especially when those producing the articles under inspection are working under a bonus scheme.

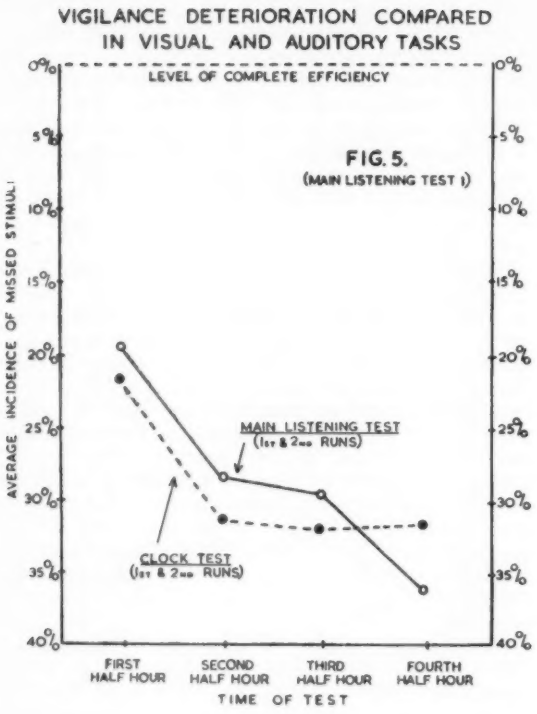
War-time studies emphasised that it would be all too easy to pass over the faintly visible electronic signals coming from an enemy submarine; these might last for only a few seconds on an airborne-radar set and the highest possible vigilance was needed to pick out these very infrequent little points of light. Operational results from the real task confirmed the laboratory findings that such alertness could only be obtained if the length of the working spell was kept as short as half-an-hour, (Mackworth, 1950). This result was equally applicable to looking (Fig. 4) and listening (Fig. 5). It seems reasonable, therefore, to conclude that this was an effect in the brain itself, rather than in the sense organs, especially as a half-hour rest was sufficient to keep the visual work accurate (Fig. 6).

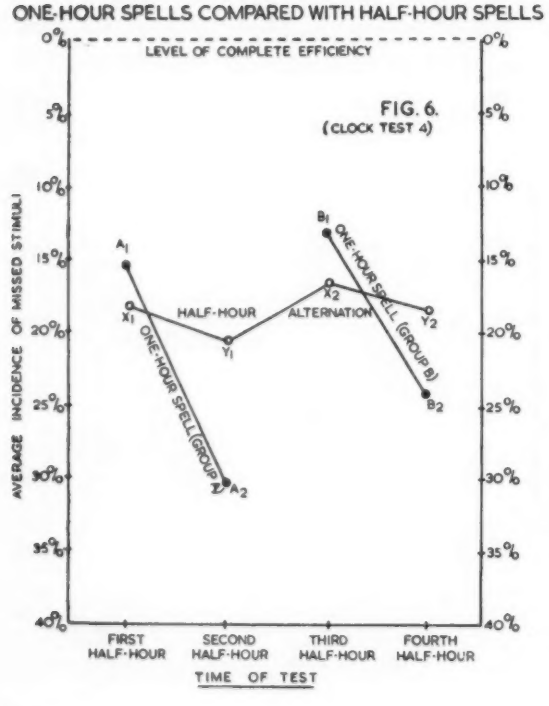
New research work is needed on the type of work which can successfully be alternated with inspection tasks to keep inspection alertness high. It is the practice in many industries to change over from inspecting to, perhaps, packing, but the most effective working arrangements are not yet known, neither the nature of the tasks that go well together in this way, nor the optimum working spell for each of the tasks. Pairs of jobs could be considered not only to avoid a falling-off at the end of the working spell — but also if possible to obtain a quick start to the work at the beginning of the spell; there is often a warm-up spell lasting a few minutes or so, even with inspection work (Mackworth, 1950).

People develop a remarkable ability to detect slight deviations from the standard object. It is possible to underestimate the potential skill of human beings, given the correct working arrangements. In one day, trained people can accurately read hundreds of chest X-rays or inspect thousands of bullets for flaws. They may let some defects pass, but they show such skill already that slight alterations in working conditions may lead to almost perfect accuracy. One possible line of research is to consider how far it might be possible to reduce the regularity in time of the signals that have to be neglected in the work or its surroundings. Some recent unpublished work by Wilkinson (1955) suggests that this may definitely handicap an operator trying to reach a high degree of accuracy.

Since both high atmospheric temperatures (Mackworth, 1950) and continuous loud noises (Broadbent, 1953 and 1954) have a marked effect on inspection accuracy during spells of work lasting more than a few minutes, it may become important to consider whether there are any other forms of stress which are also likely to be specially harmful.







The recent Annual Report by the Chief Inspector of Factories suggests that automation will increase the amount of shift-working in this country because expensive machines must be kept running as continuously as possible (Anon., 1955). This extra shift-working raises at least two questions — (1) whether inspection work is particularly difficult at any time of day or night, and (2) whether inspection work is affected by lack of sleep. Research has been started by Pepler (1955) and by Wilkinson (1955) on these two problems.

(4) *Monitoring automatic machines for emergencies*

War-time experience underlined the obvious fact that an aircraft is an extreme example of a work-place where work is machine-paced and monitoring can be remarkably difficult at times. Part of these difficulties came from circumstances which are likely to become more usual in industry as automatic processes are more widely introduced. This is the rather paradoxical situation when critical and vitally important events demanding action within a few seconds may be spaced over enormous stretches of time ; several months could elapse between the submarine contacts already mentioned.

Thirty-three lives were lost at Singapore in a civil aviation crash in 1954. The pilot of the aircraft could hardly have been more experienced, since he had in fact already landed as many as 90 times at that particular airport. (His co-pilot was however much less experienced.) The accident occurred after a night-flight from Sydney with two scheduled stops on the way.

The pilot had been just over 21½ hours continuously on duty as the aircraft came in to land at Singapore, approaching from over the sea at 100 knots. There was a light to moderate cross-wind and the daylight visibility was generally good. The runway began 7 yards from the sea-wall which was clearly marked.

Initially the pilot intended to make his usual landing on the first 50 to 200 yards of the runway. (200 yards along the runway would have been safe, but 50 yards was considered unsafe.) Visual factors, including the movement of the choppy sea against that of the aircraft, led to an initial misjudgment of height and helped to confuse his estimation of distance and ground speed, so that the aircraft approached too low.

About 5 seconds from touch-down, the pilot unhurriedly took over the throttles and increased the power. The throttles were advanced only slightly because he had by now decided to land on or near the start of the runway — instead of to overshoot the aerodrome. The wheels cleared the sea-wall at a height of 3-4 inches and touched down about 3 yards short of the start of the runway. The accident would never have occurred had the aircraft been flown even a few *inches* higher as it passed over the sea-wall.

The official comment after the inquiry was that "it is not thought that tiredness led to the initial decision to land short . . . However there can be little doubt that tiredness played a part in the pilot's ability to deal with the last 15 seconds of the

approach, which, in view of the difficult position in which he found himself, called for a high degree of judgment . . . The fact that his first point of touchdown came back closer to the threshold marking than he intended can probably be attributed to a degree of tiredness of which he may or may not have been aware " . . . (The pilot himself said that he was not fatigued; he was tired, yet no more so than usual) . . . " Although it is perfectly possible for any man, including one of the experience of the pilot, to make a mistake, I do not think he would have made this error of judgment at the beginning of a day's flying, and it is at least possible that he would not have done so after 16 hours of duty ". (Knight, 1954).

This requirement of being so alert that one can snatch up the rare event before it is too late is bound to be a hard proposition for human beings. The problem is acute when there is a time limit for effective control. The chemical industry has examples of automatic machinery which will deal with the normal situation, but which also provides a visual display of some kind to report the present situation. At the earliest possible sign of any unusual changes developing, the operator has to step in and manually operate some controls before a given irreversible change occurs in the product. Although this alarm may not occur in a given chemical plant more than once or twice a week, if these warning signals are neglected for just an extra few seconds, then a most expensive loss of product may occur.

One possible suggestion is that perhaps in some cases it would be economically worthwhile to develop displays which show not only the present position, but which give a predicted picture of the events. Taylor and Birmingham (1954a) have demonstrated the value of the 'quickened displays.' These tell the operator of manual controls at all times what he should do now, so that after the adjustment he quickly achieves the desired state. Obviously, if this can be done, it might be better to have a fully automatic system. There could be instances, however, in which the saving of a few seconds in this way by quickened displays, plus, perhaps, an auditory warning, would be all that was needed for complete success, even with the human in the control loop. For example, Broadbent (1950) has found that prolonged watchkeeping in multi-dial situations did not show any deterioration over two hours if the occasional signals for action were shown in the form of a new pointer reading or a steady light which remained there on the display until the operator manually corrected the dangerous setting. Broadbent (1953a, b and c) draws the important conclusion from this finding that the average alertness of the individual does not change with time during prolonged work, but that the level of alertness varies more and more about this average from moment to moment. The lapses in attention mentioned above become more common, but each one lasts perhaps only for a second or two at a time. Therefore a warning signal which waits even a little while for the operator to respond will not pass unnoticed. These extra few seconds could be provided before each dead-line by a display which is predicting events rather than just reporting them.

Continuous inspection and control may, however, be quite beyond human beings when manufacture must be very fast, especially if little variation is permissible in controlling the output. Automatic inspection must also be introduced when the worker runs a risk of personal injury, as, for example, in work with atomic substances. Economic reasons will press forward developments in inspection when special automatic machines have to be used and these are liable to damage either themselves or some costly product such as an aero-engine if they continue running after a breakdown. (Williams*).

The monitoring of special machines which are themselves doing a good deal of automatic sensing is clearly going to be more usual in industry. Graves* of the Austin Motor Company has shown how much has already been done in this country to introduce automatic machinery in the car manufacturing industry. He points to a danger which must be faced that " the more automation is introduced into the factory, the greater the risk of a breakdown in any one unit, stopping the whole production of the factory until the fault is repaired. Every effort must be made to make the machines as efficient as possible. The Americans claim efficiency figures of 75%-80%. Our experience varies from 65% - 80% ". Bezier* of the Renault Company underlines this by emphasising that the more expensive the plant, the less time it must remain idle. He also quotes similar figures and again he too estimates the down-time for automatic transfer machines at 20% of the working time. Tool changing is the normal cause of machine stoppages. Some of it is due to periodic tool changing, but tool breakages do sometimes occur to give automatic warning to the operator. Perhaps some of these tool breakages could be prevented and down-time reduced if, as Sargrove and Huggins* suggest, it became possible to detect fault trends in the general wear and tear on machinery and tool tips. A human monitor can then quickly replace a faulty tool before it has damaged either plant or product provided he remains alert and has a good warning system.

Bezier* is especially interesting in his views on the requirements for workers supervising special automatic machines. Safety devices automatically check the machine settings and tool conditions. The operator's work is therefore easier in many ways, but it has been made more difficult in another very important respect because there has often been an increase in his responsibilities. Lack of attention may lead to very damaging effects to the special machine mechanisms, much more so than to those of standard machines where the price is but a fraction of that of the special machine. " One has to depend upon the attention of the operator to detect any imminent failure of his safety devices and thus prevent a severe accident. To allow him to give his full attention to the working of the machine, increasing care is being taken to avoid all physical fatigue."

It is significant that no mention is made of any special effort to design really effective warning signals which say what is wrong rather than sound a general alarm. Much work has been done for pilots on electronic warning devices which call out the nature of

the danger from a pre-recorded tape (Forbes, 1952). Perhaps some particularly valuable or dangerous plant or product would justify similar devices for civil use. This is not simply a matter of ordinary seeing or hearing, but of securing immediate and correct action within a second or two at any time during a working spell lasting several hours.

Such monitoring tasks do exist and are becoming a problem in another way because they make it difficult to decide what is a fair day's pay. Physical effort is far easier to assess than mental effort. Investigations are needed on the elements of this question. For example, what are the demands made by various monitoring tasks in terms of the abilities they leave unused for other simultaneous standard tasks ? Taylor and Birmingham (1954b) have shown in continuous manual control that the human can undertake many more simultaneous activities if the work is redesigned. Perhaps this provides a way of assessing the demands of these new forms of inspection work. The method would obviously be rather crude, but it might be useful even if it could grade real inspection work tasks without any doubt into one of five levels, i.e. in terms of the mental demands of work situations ranging from simple pointer following to complex machine supervision.

There is a surprising fallacy that as long as the physical work is taken from a task, then all is well. A good example of the tendency is to be seen in the railways. Modernisation has led to some well-designed signal control centres where the signalman does not spend his days moving enormously heavy levers; a light twist of the fingers on a switch does instead. No longer does he tramp up and down in a cold and draughty signal box; he is comfortably seated in a warm and well-lit room. Responsibilities have increased already, however, since each man looks after more trains. "One of the most modern signalling installations in the world was opened in 1951 at York. Thirty-three miles of track and a series of very busy and complex junctions are controlled from a single box by a small staff. Various interlocking safety devices render it almost impossible for a signalman to make a mistake." (Davy, 1956.)

It is conceivable that responsibilities will increase yet further in the future and already the Americans are running remotely controlled trains in experimental runs near New York. It is very doubtful whether Bezier* is correct in assuming that less physical work and less routine inspection *but more responsibility* will give a task in which the amount of work required is more or less the same. We ought to try to find whether quantitative investigations are at all feasible in such circumstances and here we must try to distinguish between the extra responsibilities which mean more equipment to look after, and those that mean more serious penalties should inspection fail. It may be that the effects of extra equipment to monitor are easier to analyse than the results of greater responsibilities in the form of higher penalties for failure. Complex inspection work closely resembles decision taking of the kind discussed in the following section.

Work design for decision taking

A classic example of a factory which gives a glimpse of the future for industry is to be found in the plant for making car pistons on the outskirts of Moscow. "This factory, which supplies pistons for the entire Russian light car industry, is worked by a staff of nine men on each shift, i.e. *one general controller at the electronic nerve centre;* a labourer who loads aluminium ingots onto a conveyor at the beginning; two machine minders on the line; and five skilled maintenance men. Apart from the initial loading, all processes and all transfers throughout the 50-yard line are entirely automatic." (Lilley, 1955.)

Suppose now we consider various aspects of the work of this "general controller at the electronic nerve centre". He is said to belong to the highest industrial rank and indeed a great deal depends on the effectiveness of this one individual who is a key man if ever there was one. The whole process is under his care from the melting of the metal to the packing of the finished pistons.

The main task for the controller is related to the locating of any breakdown in the production line. "Practice in operating automatic machine tool lines and the automatic factory shows that with correctly arranged maintenance and repair of the electrical equipment, correction of maladjustments arising in the operation of the electrical equipment and electric automatic devices can be carried out comparatively quickly. Considerably more time is normally expended in establishing the cause of the maladjustment and identification of the defective apparatus. Actually, with a very large number of apparatuses taking part in the working cycle of the line, the complex control circuit and the great extent and ramification of the control circuits, quick determination of the cause and location of a fault is sometimes a matter of considerable difficulty and a task only for highly qualified maintenance personnel. From this point of view correct construction of the control system and a circuit facilitating rapid fault location is very important . . . " (Zusman and Minsker, 1952.)

"An automatic control system provides automatic signalling which indicates the unit responsible for malfunctioning of the line or section. This at once greatly reduces the field of search and makes it possible by quickly examining the elements of the unit in question to find and consequently to correct the defect. Special (automatic) fault finders for finding faults within individual machine units, as practical working has shown, did not justify themselves and were subsequently omitted." (Zusman and Minsker, 1952.)

The controller has, in fact, to send in the maintenance men to look at the particular machine unit causing the trouble. How does he do this ? He sits at a desk which is shown in Fig. 7. This provides him with a panoramic view of the factory which shows the state of the equipment at a glance. Under the transparency are sections arranged to correspond to each machine unit, and from Fig. 7 there appear to be 18 such check-points along the line.

Each of these sections can show one of three signals :

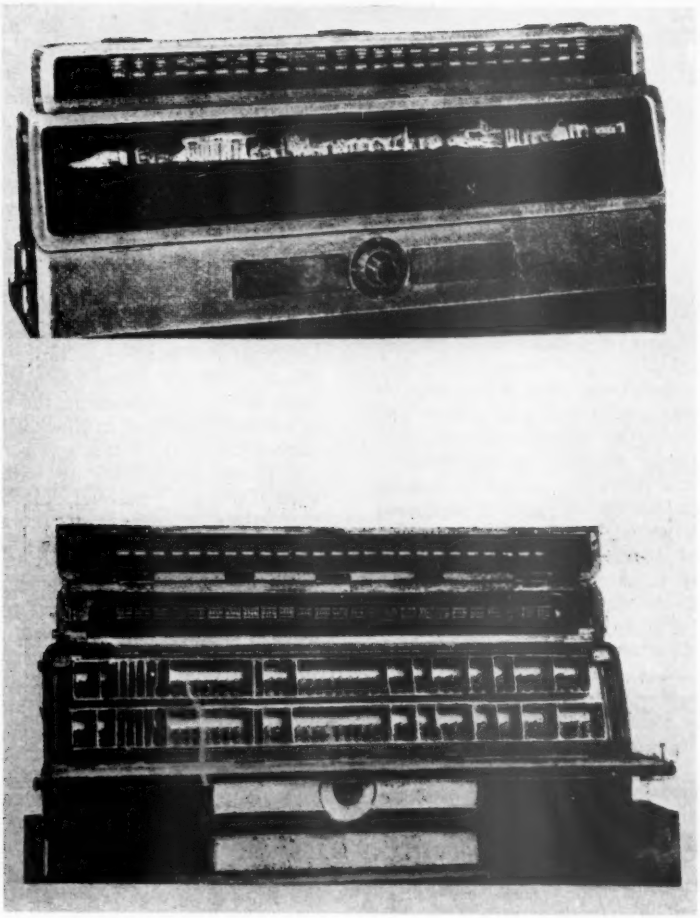


Fig. 7.

1. *Dark* — "Machine unit not switched on".
2. *Light* — "Machine on".
3. *Bright* — "Emergency here".

The same code is used on the corresponding machines. Some details on the electrical arrangements may be of interest. Each section in the desk panel contains two groups of 24 volt d.c. flashlight bulbs which are connected in series with the circuit for the corresponding machine unit.

1. *Dark* — No current passes through the lamps for that section because the given machine unit is not switched on.
2. *Light* — As soon as the knife-switch on the machine unit is switched on, an intermediate control relay is connected and connects both groups of lamps in the corresponding section. The lamps in that section therefore light at half brilliance.
3. *Bright* — Each machine has an emergency relay which short-circuits an additional resistance. The second group of lamps in that section therefore burns at full brilliance. (Zusman and Minsker, 1952.)

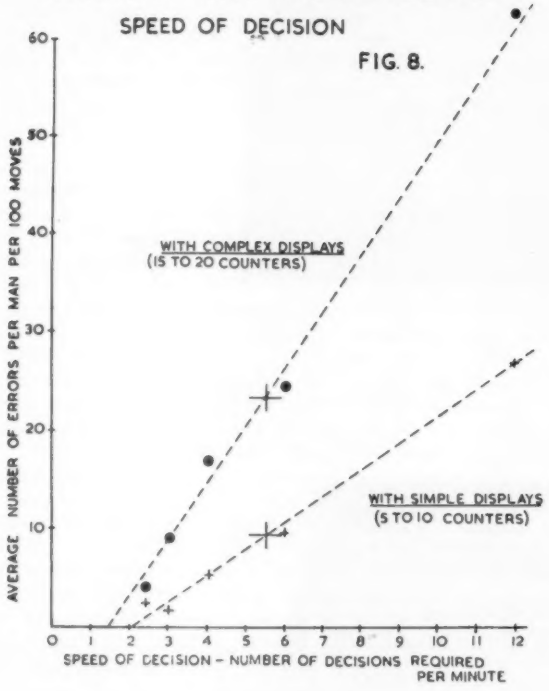
It will be seen from Fig. 7 that the controller can also look at a row of 25 four-figure telephone counters. These are continuously adding up the output at different stages along the line and give the present production position as regards:

1. number of ingots fed into smelter;
2. number of blanks cast;
3. number of pistons undergoing heat treatment;
4. number of serviceable blanks and rejects checked for hardness;
5. number of tinplated pistons;
6. number of pistons sorted into groups;
7. number of boxes packed.

This type of display for general industrial control may become more common in the years to come. There are a number of decision-taking problems of very great interest in a situation of this kind. Some of these jobs are basically machine-paced tasks in which the controller has to select the correct orders based on the information all of which is on the panel in front of him, and he has to do this as quickly as possible. He has in fact to search for a series of decisions to ensure that a number of objects arrive at

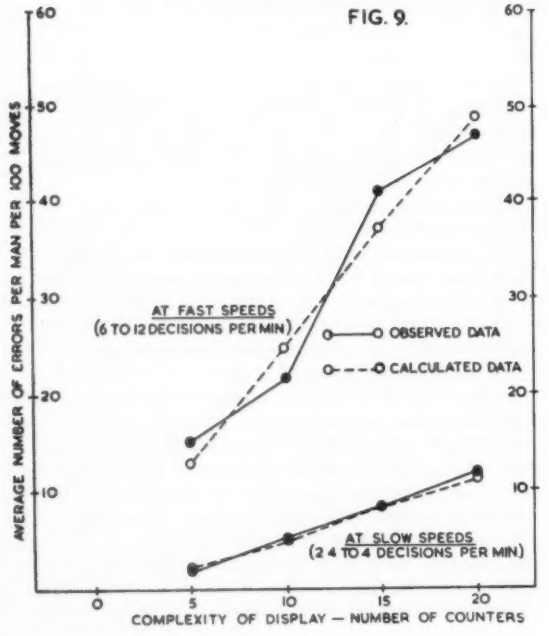
EFFECTS OF INCREASING THE REQUIRED SPEED OF DECISION

FIG. 8.


AVERAGE NUMBER OF ERRORS PER MAN PER 100 MOVES
WITH COMPLEX DISPLAYS (15 TO 20 COUNTERS)
WITH SIMPLE DISPLAYS (5 TO 10 COUNTERS)
SPEED OF DECISION – NUMBER OF DECISIONS REQUIRED PER MINUTE

EFFECTS OF INCREASING THE COMPLEXITY OF THE DISPLAY

FIG. 9.


AVERAGE NUMBER OF ERRORS PER MAN PER 100 MOVES
AT FAST SPEEDS (6 TO 12 DECISIONS PER MIN)
OBSERVED DATA
CALCULATED DATA
AT SLOW SPEEDS (2 4 TO 4 DECISIONS PER MIN)
COMPLEXITY OF DISPLAY – NUMBER OF COUNTERS

the right place at the right time. A laboratory task has been devised which presents a similar problem for analysis. People have to search through a display panel to find urgent decisions which, if taken correctly, will ensure that the movable objects on the panel will arrive at their various destinations according to a definite timetable.

One problem is that of the pace set for the task as a whole. Fig. 8, for example, shows how the average error score for 20 men rose when more and more decisions were demanded per minute. This was done by speeding up the clock on which the timetable was based.

A less obvious problem than speed stress is the effect of the number of objects being shown on the display. Even when the pace is reduced in proportion to the increase in the number of units, there is a considerable effect due solely to this aspect of the perceptual load. For a given average speed of work, the errors will mount up with more items to consider if delay is penalised. Fig. 9 shows, however, that this effect is made even more serious when speed stress is added to load stress (Mackworth and Mackworth, 1956b.)

Conrad (1951) has shown, too, that twice the load and half the speed of work does not lead to the same level of achievement as before. Doubling the number of spindles which a worker has to watch produces difficulties which may not be removed by halving the rate at which each spindle requires attention. Laboratory studies help to tell us how this comes about. First, as in Fig. 8 and Fig. 9, every extra item added may bring with it more and more signals of no importance which have to be neglected, and which hamper visual search. Obviously there will be more difficulty in finding the next urgent signal from amongst a hundred signals than in picking the next one from twenty signals. Correcting the time allowed to the extent only of making the number of decisions demanded per minute the same as before will not compensate for this difficulty when, as it were, the controller is being blinded by insignificance. For example, to pick out a two-figure number by eye from a few score such numbers will take about four times as long as choosing the same pair from only half a dozen. (Baker, 1955.)

Secondly, the introduction of extra items to watch can lead to trouble in a rather different way, and this can occur even when the *average* pace set by the machine is relatively slow; here, the basic trouble arises when two or more signals overlap in time and both signals have to be seen immediately. Signal overlap can obviously take place even when the decisions demanded per second are relatively few. It has been shown that under certain conditions a good index of the difficulty due to signal overlap is the number of seconds that any given signal overlaps with any other signal (Mackworth and Mackworth, 1956a).

This signal overlap problem is likely to arise when a controller is given a pair of cathode-ray tubes to watch simultaneously. The possible introduction of closed-circuit television monitors in industry may make the following instance perhaps less light-hearted

than it might otherwise have been. Modern man is already faced with two television programmes in England. One dramatic critic has mentioned his ability to look at these two programmes simultaneously by having the right-hand set tuned to the B.B.C. and the left-hand one to I.T.A. Suppose, however, the critic is trying to note down the names in a series of credit titles at the end of two plays. As the names flash past, he will obviously be able to get the names down accurately if he can alternate successfully from one source to another. But every now and again, provided the names are coming in at a different rate on the two screens, there will be trouble when he ought to look in two places at the same time. (Such arrangements do occur at times, and it is no solution for the controller to lunch well, and to hope that he can follow the different movements on the two screens separately with one eye on each picture.)

Seriously, however, the detailed study of eye-movements in relation to changing simultaneous displays of this type may be very rewarding. There would usually be no problem in deciding in which order to take the screen names as they would appear in a fixed and pre-determined series, but obviously in, for example, the Russian display two or more emergencies might flash on and demand simultaneous action. This is the third problem that may arise from simultaneous signals on a display ; the decision as to the correct sequence may give some difficulty especially if their order of arrival has to be remembered, or if one emergency should have priority. Some recent unpublished work has shown that at very fast decision speeds, when a whole series of questions has to be answered, it may be best to show only the present problem and the one after that. At slow speeds, however, it is better to give three problems ahead rather than two, so that the operator may have time to plan his moves. Perhaps at very fast speeds it is more difficult to remember the relative order of the incoming problems (Mackworth and Mackworth, 1956b).

Electronic presentations make it possible to ensure that people take their turn in, for example, a telephone exchange where the operator sees only the present call and knows that someone else is waiting. The machine automatically regulates incoming calls into an orderly queue and as soon as the operator has dealt with one call the next one appears. This is better than a Christmas tree effect on the panel, which may lead to nothing but confusion.

It is often, however, not enough to take things as they come, and machines can, of course, be devised to give priority to signals from any specially important sources. No one who is working fast should have to search and pick out these priority signals for himself. Telford* made much the same point in discussion when he emphasised the advantages of automation in improving the quality of information provided to directors and management by an automatic office. The computer may print its "answer" in a book several inches thick and on each double foolscap page there may well be nothing but rows and rows of numbers. But the computer *can* also compress and digest information into its salient features. It is therefore up to the management to decide for the computer designers just what information is going to be essential for the particular executives they have in mind — first, as regards the basic facts needed, and secondly, how these should be expressed. Experimental studies might then be useful to test various alternative ways of presenting the facts ; experiments might even help to decide the irreducible minimum of information. These investigations would be undertaken by progressively paring away the material until comprehension began to fail, i.e., rather as a block diagram of a circuit is simplified from a detailed circuit diagram.

Nowadays many executives are choked with the quantities of reading matter that arrive on their desks. Time could be saved by inter-office competitions to minute the same messages in fewer words. How *few* words can come between need and action ? Improve through-put rather than output.

Many planners of office computers have erred in aiming to produce more data than management has been able to find time to digest. The function of the office computer should be to simplify information so that management is presented only with significant data. "Mere volume of output is of no value to management. The computer can be put to work on a process of detection, sifting rapidly the evidence presented so that the real culprit can be identified amongst a mass of suspects." (Hooper*). One way of obtaining the best man-machine relationship in thinking problems is at times when the man asks the machine which of a number of different alternatives is the correct answer. He can do this by pressing a series of buttons according to the various possibilities. This approach combines the flexibility of the human brain with the remarkable speed of the electronic brain.

Hooper* makes the further point that when people dream about members of the management sitting before screens showing exactly what is happening from moment to moment, "it must always be remembered that a computer cannot think originally or intuitively, determine its own instructions or perceive or interpret any situations which may arise outside the precise instructions to it". Although this is true, I believe that more use might be made of the limited amount of *machine prediction* already possible with existing servo-systems. McCallum* gives Fig. 10 as an example of the considerable progress made in the control room layout of the petroleum industry. This shows "not only the conventional type of instrument layout, but also the graphic panel system which is a fairly recent development. The graphic panel, using a small type of instrument, incorporates a picture of the flow through the unit by arranging the instruments on a simplified flow plan and so giving the operator a more logical representation of the way the plant is operating. From this central control room the whole plant is run and if any of the variables drift away from desirable levels, then there is a system of alarms which warn the operator that adjustments are necessary".

McCallum* mentions, however, that "a large number of temperature measurements are also

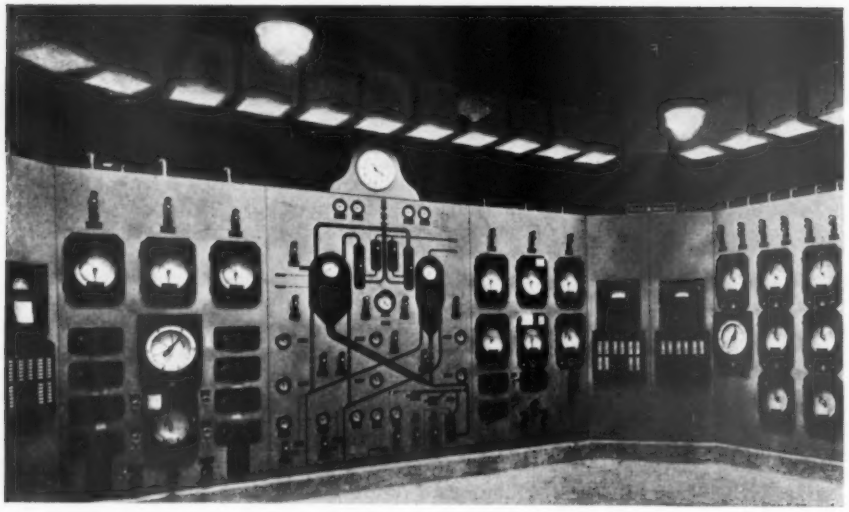


Fig. 10.

brought into the control room so that periodical checks can be carried out on various parts of the unit which are not under automatic control". Obviously a great deal of thought has gone into this central control room, and it is clearly superior to many in use today. But I am left with the feeling that in general even more could be done to improve the presentation of information in rooms of this kind, e.g., to find the present state of the plant it seems necessary to look at a large number of rather separated displays. If certain displays are used a great deal, they should be placed together so that it would be easier to relate one reading with another.

This approach would become particularly important in cases where the controller was trying to *predict* the immediate outcome of the present situation (Poulton, 1950, 1952a and b). When machine prediction is impossible for technical or economic reasons, it is specially important to assist the human in his efforts to forecast an imminent emergency. It is not unknown for such prediction to be expected from controllers when they have mentally to combine data from counter readings, pointer readings, rising graphs and changing lights. Less diversity in the signal source would seem to be desirable when the human is trying to find an important trend in the changing scene.

Let me, however, end this rather futuristic section on a note of admiration for engineering efforts to make the machine an effective controller, in case I should be thought to be biased in favour of human thinking. Young* mentions the possibility that a computer could not only control a chemical plant, but it could at the same time gradually determine the best operating conditions for that plant by finding those likely to give the highest yield of the given product. There is something completely fascinating in this idea that this master computer could solemnly carry out the necessary experiments by following a well-balanced statistical plan fed into it by the plant manager. McCallum* goes further and adds that "to establish whether a petroleum plant is running at a level of optimum profitability it is necessary to carry out very lengthy and time-consuming calculations. These calculations can readily be done on a computer, and it should be possible in the future to integrate such calculations with direct control of operating variables in the unit". Feed-back for self-service is to be expected nowadays, but this kind of self-help and self-advancement is quite remarkable.

Part 2. Training of Electrical Maintenance Workers

It is a striking fact that two-thirds of those who addressed the 1955 Margate Conference mentioned this problem of the maintenance of automatic machinery. No other matter drew quite so much attention as this topic, which occurred in as many as 14 of the 21 Papers presented at the meeting.

Garner*, for example, stated that "although automation eases the burden of operators, it is the reverse for those skilled machinists, fitters, electricians, testers, etc., who manufacture, develop and maintain the automatic equipment which may vary from the most simple to the very complex". Peacock* also took the view that "the expanding use of electronic equipment has already shown the need for a new type of maintenance engineer and the demand for this class of skilled labour may well bring about a major redeployment of labour in the factory of the future". Young* noted that "already the great majority of the men employed in the chemical industry are engaged on maintenance, new installations and so on. The operators are a very small minority . . .". Then again, in the Russian piston plant we have already seen how five men out of a total staff of nine were maintenance engineers.

The economic need for good maintenance becomes obvious if automatic machines can at best be kept

running for 80% of the available time (Graves* and Bezier*). The outstanding importance of good maintenance from a safety point of view is equally clear. Fletcher* emphasised that automatic machinery may not only increase production, but will reduce the incidence of accidents. The fine accident record of the London Underground provides an instance of this. But the human factor comes in even here because one of the very few serious accidents on the Underground arose because a maintenance man made a mistake in connecting an electronic relay (Davy, 1956). This recalls the comment by Old* to the effect that as industrialisation proceeds, the skilled man is removed further and further from the finished product, but he is always somewhere in the series of events.

Woollard* predicts that in the automatic factory "on the shop floor there will be more tool setters, maintenance men and technicians allocated to each group of machines . . . There will, of course, be viewers until the inspection becomes automatic, then the viewer will become an electronic technician. It will be observed that most of the men must be first-rate mechanics and, if they have not already acquired, they will be approaching supervisory status. They will be keen and intelligent men ; they will have little to do much of the time, but will be ever on the alert and quick in action when action is required . . . They must be highly responsible men".

Already this double requirement of high-grade intelligence for the maintenance of complex machinery plus exposure to long spells of inactivity is a situation causing some anxiety, because not enough able people are willing to do this type of work. This sounds as if it were a situation of the type mentioned by Seaman* in which the responsibility lies squarely on management to study the balance between (1) the job, (2) leisure and (3) training — a matter which should constantly be kept under review.

Woollard* made the interesting further comment that "time study as a shop-floor technique will disappear because time study will be a preliminary to the design of machines and will be, so to speak, built into them". Graves* also drew attention to the real requirement to design automatic equipment for easy maintenance. Paradoxically, it is necessary to stress that training for maintenance should begin with the simplification of the maintenance task. Not nearly enough has been done to ensure that electrical and mechanical equipment is easy to maintain as well as to operate.

Woollard* underlines the need for a series of short courses in mechanics and electronics, for the shop-floor employees. Bezier*, too, suggested that it is possible to imagine a team of maintenance men with both mechanical and electrical knowledge. These maintenance men are certainly going to come from the shop-floor, but as Fletcher* said "it is not enough to point out to displaced semi-skilled machine minders or to a group of clerks the growing demand for designers, engineers, electricians and instrument makers". There must be re-training schemes where machine-minders are given the elements of an electrical education.

Today or tomorrow the routine operator may be temporarily out of a job because some new machine is now doing his job much better. How can you train him to undertake the much less strenuous but more highly skilled work of caring for that machine and others ? There seem to be two alternatives. One way is to train him for front-line maintenance (i.e., to locate the fault and either to repair it quickly there and then, or to replace the defective electronic unit). The other way is to embark on a much more ambitious programme which will produce a competent electronic technician. The second method gives a man who is able to repair the defective unit after its removal. The usual bottle-neck in maintenance is in the immediate location of the fault rather than its repair, and as mentioned previously, the Russian experience confirms this. Front-line maintenance is, therefore, the problem that will be considered first. What form of short-course in elementary electronics might, for example, be given at evening classes or during one-day-a-week training to change machine-minders into fault-finders ?

It would be possible to try to answer such a question to some extent in general terms by turning to a handbook on training such as the excellent volume by Miller, 1953. This takes up five of the main aspects of training in its 339 pages :

1. How to give the learner his knowledge of results in such a way that he will get the maximum benefit from his responses. (Practice by itself does not make perfect ; there is no learning without some feedback.)
2. Motivational problems and the use of non-financial incentives. (See also the Paper by Gibbs and Brown, 1955.)
3. How to recognise the essential features of a real job for simulation and training purposes so that experience on the artificial form of work will help rather than hinder subsequent performance on the real job.
4. The use of simulation devices to demonstrate principles.
5. How to specify the design requirements for training equipment.

Then again Wolfle (1951) has an excellent general chapter on training regarded as the applied psychology of learning — and Seymour (1954) has recently published a volume on industrial training for manual skills. These general references are important — but I imagine it would be better here to give concrete instances from investigations directly related to electrical training.

Learning Electrical Ideas by their Use

Johnson (1951) has been working on the evaluation of a more effective method of training electronic technicians for the U.S. Navy. These were men of 18 to 20 years of age who had to be given the rudiments of the subject in as short a time as possible, without lowering standards of knowledge or practice. None of the learners had any previous direct experience of electrical matters.

The *usual method* of instruction was compared with the *experimental method*. Seventy men took part in each section of the experiment. These two groups of people were matched for general ability and education by ensuring that for each man in one group it was possible to find someone in the other group who was similar in both respects.

The *usual method* divided the time equally between lecture and laboratory, with the lectures subdivided into mathematics and theory. The laboratory experience was intended to give practical exercises in applying the theory and the mathematics. Laboratory classes were about 30 men per instructor, and lecture classes ranged in size up to about 60 students for a single instructor. One instructor taught two periods of mathematics daily, a second instructor gave two periods of theory and a third instructor did four periods of laboratory work. The course was described as being academic with little credit for practical work.

The *experimental method* was designed to bring together practice and theory more closely, each class had its own instructor in the same room throughout the course, and the same man taught all the laboratory work, theory and mathematics. Class size was limited to 15. The essential point of this method was, however, that the students learned the more abstract subjects as they built electronic apparatus. There was a greater emphasis on practical work and the mathematics taught was limited to that which was essential to understand the theory or the laboratory constructional work. The theory and mathematics were introduced in such a way that they were taught when and where they were needed to undertake the laboratory work.

The results were that the 70 people in the *experimental group* needed only 18 weeks to reach the same level as the *usual group* reached in 26 weeks. No differences in knowledge could be found between the groups on a series of multiple-choice questions concerned with shop practice and direct and alternating current. Similarly, no differences could be found between the two groups during a subsequent spell of 16 weeks under very careful observation of their daily practical work with actual electrical equipment.

Another way the results were analysed was to consider the training wastage, and the number of repeat periods of instruction during the course. Six men had to be rejected from the *usual group* and none from the *experimental group* (apart from two who dropped out from illness). As many as 31 of the 70 men in the *usual group* had to have repeat periods, lasting usually one to two weeks during their course, and this was in striking contrast to the *experimental group*, none of which required any repeat instruction.

Many different reasons were believed to have contributed to the advantages seen with the experimental course. First of all, in the usual course, two days out of ten were spent in review and examination. In the experimental course each day's work opened with a review of the previous day, and no special day was allocated for a review. The learner was undertaking a good deal of self-review because he was constantly having to build into his equipment the subject matter he had just learned. By learning as he built, the student was teaching himself much of the time, with however advice when needed. Secondly, this combination of theoretical and practical work made it possible for the student to work on simulated work situations. A close relationship was established between learning activities and needs, and this eliminated a considerable amount of subject matter specially on the mathematical side, without reducing in any way either the practical or general efficiency of the students. Thirdly, frequent brief examinations were used as teaching devices in the experimental course to discover any weak spots in knowledge as quickly as possible.

Obviously there are many differences between training in an American Services situation and training in an industrial situation in Britain — and this method of teaching may indeed already be fairly well known here. The main purpose of presenting this example is not only to give one possible approach to short-course instruction, but also to illustrate a quantitative way of thinking about the *evaluation* of training methods. It is particularly in this quantitative way of considering training that applied experimental psychology has much to contribute (and much to learn), as for example, in the measurement of achievement during and after training.

Measurement of Fault Location

Simulation of the tasks facing electronic maintenance men, although not easy, is much less difficult than it would be in many other forms of work. Technical colleges are now using this approach of actual circuits which provide standard faults as training devices in the diagnosis of particular defects. It is thought, however, that there is a whole new field for research on the question of how people do, in fact, locate faults in a circuit. Surprisingly enough, much less is known about this than about predictions on the most satisfactory way to find a defect (Miller, Folley and Smith, 1953 ; Gagné, 1954).

Dale (1955) in some interesting unpublished work describes how he has started to investigate fault location. Twenty-four untrained adults were provided with a series of problems which took the form of a number of items arranged in chains. Fig. 11 shows that these chains had several input and several output terminals. The subjects were told to find the faulty item in the "circuit" and were asked to begin each problem by checking every input and output terminal. They were then to proceed by checking one item at a time, taking these in any order but always attempting to make as few checks as possible in locating the one faulty item. (These items were small cardboard squares bearing marks representing (1) input correct and output correct, or (2) no input and no output. One card was the faulty item and this had (3) input correct but no output. These squares were placed face downwards to provide the need for search among the items.)

The logical way to solve this problem was to begin by making a check such that the probability that the fault lay towards the input side of this check was equal to the probability that it lay towards the output

side. With branching chains, however, it was better to start checking at points which would eliminate whole branches of the system. To find the fault in the circuit shown in Fig. 11, for example, a total of five checks is sufficient, and one possible solution is given in Fig. 12.

Less than one half of the checks actually made by the 24 untrained men were placed at the most favourable points in the system. There was a tendency to be over-cautious, i.e., to make checks which were too close to the previous check and, therefore, provided very little additional information. One possibility that is now being considered by Dale (1955) is to discover whether the choice of check points is modified by the actual lay-out of the circuit diagram.

This work needs confirmation by the presentation of similar problems to trained electronic fault-finders, but it has already brought up the possibility that training in the best methods of search might reduce the time and effort required to pin-point a fault in an electrical circuit. Many other factors have to be introduced into the experiment. It is believed that the investigation has implications rather more for fault-location within a given machine unit. It may, however, also be useful in first-line maintenance under circumstances where no effective warning light system indicates the faulty machine unit. In the first-line maintenance problem each machine unit is to be regarded as a component in the "circuit", which then becomes a "block diagram". The main objectives of further work are to elucidate the factors underlying effective training in fault-location. The method is to consider what people do in fact do, in addition to what they ought to do and what they might do.

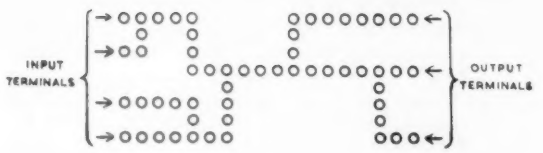
The Future Supply of Electronic Staff

The more that machines take over the tasks of industry, the more highly trained the maintenance men will have to be. There are many people today who believe, and find their belief confirmed by life, that education is useless after you have learnt to read the daily paper and to do the football pools. Mathematics is for them useless drudgery, the learning of the multiplication table to be promptly forgotten along with everything else placed before them at school. Yet boys spend the ten most formative years of their lives at school, and almost every child is filled with a passionate curiosity to find out about everything. Somewhere along the line the most valuable asset of the human race is destroyed and in its place comes the desire to get by with the least effort. If you want, as you will, millions of men able to understand electricity, it is necessary to go right back to the early days of school to use and keep alive that invaluable curiosity. Nothing is more difficult than learning to talk, or to read and write, things which all but the very lowest grade take in their stride.

The child needs to know the use of what he learns. Teach him abstract mathematics and incomprehensible ideas about gravity and gases, and he is

CIRCUIT PROBLEM

FIG. 11.



lost to learning for ever. But put a child old enough to have sufficient manual dexterity on to building his own transistor receiving set, and he is ripe to learn how it works and why. Education should be primarily aimed at making, for man is a maker before he is a thinker, and most of the best thinking comes from trying to understand how and why things act as they do.

So training must start in the schools, and the elementary schools at that. For this you need new teachers, a vast amount of new equipment and new examinations. Since none of this is likely to come from the Government, industry might use some of the money it now pays in taxes to found its own schools. However, this is, perhaps, in the very distant future.

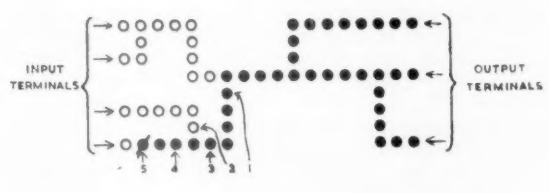
Acknowledgments

It is a real pleasure to acknowledge once again the help received from Sir Frederic Bartlett, F.R.S., during discussion of these questions. Much assistance in the preparation of this Paper came from my wife. I am also greatly indebted to members of the Medical Research Council Applied Psychology Research Unit, mentioned in the text, who were kind enough to permit reference to their current research. Mr. E. R. F. W. Crossman of the Department of Engineering Production at Birmingham University and Mr. B. Shackel of E.M.I. Engineering Development Ltd., Hayes, also assisted with their advice.

The essential and generous background support for these investigations came largely from the Medical Research Council and the Personnel Research Committees of the three Services, with further help from Conditional Aid funds.

CIRCUIT ANSWER

FIG. 12



○ REPRESENTS A STAGE WHICH HAS BOTH A CORRECT INPUT AND A CORRECT OUTPUT.

● REPRESENTS A STAGE WITH BOTH FAULTY INPUT AND FAULTY OUTPUT

REPRESENTS THE FAULTY STAGE, ITS INPUT BEING CORRECT, ITS OUTPUT FAULTY

REFERENCES

1. BAKER, C. H. (1955). Personal Communication.
2. BARNETT, G. 1954 Annual Report of the Chief Inspector of Factories. H.M. Stationery Office, Kingsway, London, W.C.2.
3. BROADBENT, D. E. (1950). The Twenty Dials Test under Quiet Conditions. Med. Res. Council A.P.U. Report 130/50.
4. BROADBENT, D. E. (1953a). Neglect of the Surroundings in relation to Fatigue Decrement in Output, Chap. in Fatigue, 173 - 178, H. K. Lewis & Co. Ltd., London.
5. BROADBENT, D. E. (1953b). Noise, Paced Performance and Vigilance Tasks. Brit. J. Psychol., *44*, 295 - 303.
6. BROADBENT, D. E. (1953c). Classical Conditioning and Human Watch-keeping. Psychol. Rev., *60*, 5, 331 - 339.
7. BROADBENT, D. E. (1954). Some Effects of Noise on Visual Performance. Quart. J. Exp. Psychol., *6*, 1 - 5.
8. CONRAD, R. (1951). Speed and Load Stress in a Sensori-motor Skill. Brit. J. Indus. Med., *8*, 1 - 7.
9. CONRAD, R. (1954). Speed Stress. Chap. in *Human Factors in Equipment Design*, 95 - 102. H. K. Lewis & Co. Ltd., London.
10. CONRAD, R. (1955a). Setting the Pace. The Manager, *23*, 664 - 667.
11. CONRAD, R. (1955b). Adaptation to Time in a Sensori-motor Skill. J. Exp. Psychol., *49*, 115 - 121.
12. DALE, H. C. A. (1955). Searching in a Structured System. Med. Res. Council A.P.U. Report 247/55.
13. DAVY, J. (1956). Safety on the Railways. Observer, Jan. 8, 1956.
14. FORBES, T. W. (1952). Auditory Signals for Instrument Flying. Chapter in Readings in Experimental Industrial Psychology, 227 - 233, Prentice-Hall, Inc., New York.
15. GAGNE, R. (1954). An Analysis of Two Problem-Solving Activities. Research Bulletin AFPTRC-TR-54-77. Lackland Air Force Base, San Antonio, Texas, U.S.A.
16. GRIME, G. (1954). Vehicle Characteristics and Road Accidents. Effects of Design and Maintenance. Engineering, Sep. 10, 1954, 339 - 344.
17. GIBBS, C. B. and BROWN, I. D. (1955). Increased Production from Information Incentives in an Uninteresting Repetitive task. The Manager, *24*, (to appear).
18. JOHNSON, H. O. (1951). The Development of More Effective Methods of Training Electronic Technicians. H.B.M. 22/1 Appendix. Dept. of Defence Research and Development Board, Washington, 25, D.C., U.S.A.
19. KNIGHT, C. (1954). Report of the Public Inquiry into the causes and circumstances of an accident which occurred on March 13, 1954, to the Constellation Aircraft G-ALAM. Col. No. 312. H.M. Stationery Office, Kingsway, London, W.C.2.
20. LILLEY, S. (1955). Automatic Factories. Discovery, *16*, 147 - 152.
21. McFARLAND, R. A. et al. (1953). Human Body Size and Capabilities in the Design and Operation of Vehicular Equipment. Harvard School of Public Health, Boston, Mass., U.S.A.
22. McFARLAND, R. A., DUNLAP, J. W. et al. (1953). Human Factors in the Design of Highway Transport Equipment: a Summary Report of Vehicle Evaluation. Harvard School of Public Health, Boston, Mass., U.S.A.
23. McFARLAND, R. A. and MOSELEY, A. L. (1954). Human Factors in Highway Transport Safety, Harvard School of Public Health, Boston, Mass., U.S.A.
24. MACKWORTH, N. H. (1950). Researches on the Measurement of Human Performance. Med. Res. Council Special Report Series No. 268. H.M. Stationery Office, Kingsway, London, W.C.2.
25. MACKWORTH, J. F. and MACKWORTH, N. H. (1956a). The Overlapping of Signals for Decisions. Amer. J. Psychol., *69*, (to appear March, 1956).
26. MACKWORTH, N. H. and MACKWORTH, J. F. (1956b). Searching for a Series of Decisions. Med. Res. Council A.P.U. Report 234/56. (In preparation.)
27. MILLER, R. B. (1953). *Handbook on Training and Training Equipment Design.* W.A.D.C. Technical Report 53 - 136. Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, U.S.A.
28. MILLER, R. B., FOLLEY, J. P. and SMITH, P. R. (1953). Systematic Trouble Shooting and the Half-split Technique. Technical Report 53 - 21. Lackland Air Force Base, San Antonio, Texas, U.S.A.
29. PEPLER, R. D. (1955). Personal communication.
30. POULTON, E. C. (1950). Perceptual Anticipation and Reaction time. Quart. J. Exp. Psychol. *2*, 99 - 112.
31. POULTON, E. C. (1952a). Perceptual Anticipation and Tracking with Two-pointer and One-pointer Displays. Brit. J. Psychol., *43*, 222 - 229.
32. POULTON, E. C. (1952b). The Basis of Perceptual Anticipation in Tracking. Brit. J. Psychol., *43*, 295 - 302.
33. *PUCKEY, W. et al. (1955). *The Automatic Factory — What does it Mean?* Report of the Institution of Production Engineers Conference at Margate, 1955. E. & F. N. Spon (Publishers), 23 Great Smith Street, London, S.W.1.
34. SALDANHA, E. L. (1955). An Investigation into the Effects of Prolonged and Exacting Visual Work. Med. Res. Council A.P.U. Report 243/55.
35. SEYMOUR, W. D. (1954). *Industrial Training for Manual Operations.* pp. 203. Sir Isaac Pitman & Sons, Ltd., London.
36. SIDDALL, G. J. and ANDERSON, D. M. (1955). Fatigue during Prolonged Performance on a Simple Compensator Tracking Task. Quart. J. Exp. Psychol., *7*, 159 - 165.
37. BIRMINGHAM, H. P. and TAYLOR, F. V. (1954a). A Human Engineering Approach to the Design of Man-Operated Continuous Control Systems. NRL Report 4333. Naval Research Laboratory, Washington, D.C. (See also Proceedings of the Institute of Radio Engineers, 1954.)
38. BIRMINGHAM, H. P., KAHN, A. and TAYLOR, F. V. (1954b). A Demonstration of the Effects of Quickening in Multiple Co-ordination Control Tasks. N.R.L. Report 4380. Naval Research Laboratory, Washington, D.C.
39. WILKINSON, R. T. (1955). Personal communication.
40. WOLFLE, D. (1951). Training. Chapter in *Handbook of Experimental Psychology.* John Wiley & Sons, Inc., New York. pp. 1436.
41. ZUSMAN, V. G. and MINSKER, E. I. (1952). The Electrical Equipment of an Automatic Piston Factory. Avtomatikai Telemekhanika, *13*, 282 - 312.

REPORT OF THE MEETING

at the Royal Institution, London.

Thursday, 9th February, 1956

In the Chair: Mr. G. Ronald Pryor, Chairman of Council.

THE **Chairman** said it gave him great pleasure to welcome Dr. Mackworth, of whom there was a brief biography in the preprint of the Paper.

It would be agreed that this was a most remarkable Paper. Most people had heard Papers by industrial doctors from time to time, at least at school level; but it was very rare indeed to read or hear a Paper such as this by a doctor of medicine who displayed such an intimate knowledge of engineering. Dr. Mackworth really did speak the language of engineers and could talk about the things they understood rather than about microbes and such matters. In fact, had the Paper not had a name attached to it, one would have taken for granted that it had been written by an engineer.

Dr. Mackworth had underlined his Paper with examples of a quite dramatic nature which made exciting reading. It was a great compliment to the Institution that he had read so closely and absorbed so well the Institution's publication "The Automatic Factory": no less than over thirty of his references came from that work.

Finally, it would probably be agreed that not the least significant part of the Paper was contained in the recommendation at the end, which was most far-seeing and quite significant.

Dr. Mackworth, in presenting his Paper (which appears on pages 214-228), said he would like to make yet one more reference to the Margate Conference. Mr. Fletcher, at the Margate meeting, made the arresting and striking statement that there was a good deal of *dark* about automation and the so-called automatic factory — and a good deal of loose talk as well. There did seem to be a certain amount of confusion. For example, the Chief Inspector of Factories, in his current report, talked of mechanical handling machines being devised "with an almost bewildering frequency". "If I may be allowed to add to the loose talk," Dr. Mackworth continued, "I might perhaps say that people are adrift on a flood of machines. It is dark. There is no sun and there are no stars to guide us; and there are no trade winds either. How do we find our way back to land? How do we find the all-important human problems for individual efficiency in industry?

"The procedure I have adopted is a very old one—one of the earliest navigational devices much used by ancient seafarers—the release of a few birds to find the direction of the shore. If, after circling round and round, these birds eventually tend in a definite direction, it is reasonable to assume that they have seen land that way. Simple and primitive, this is, of course, the empirical method used by the earliest of known navigators. Like Noah, what we are doing today, then, is to send up several birds in the shape of ideas to watch them circle during discussion, in order to see which way the land really lies.

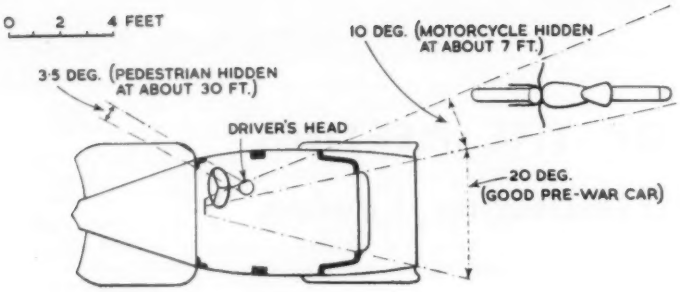
"Noah tried four times—first with the raven and then three times with the dove. In the Paper I have done much the same. First let us consider the raven—the commonsense approach to work design—as this obviously should have first try.

"I take the view that commonsense is able to tackle many problems in work design, but that by itself it may not be enough. Commonsense has, of course, a great part to play and, indeed, more could be done than is actually done along these lines.

"In this country every year more than five thousand lives are lost on the roads. It is therefore commonsense that the driver of every car ought to be able to see out of his vehicle. Yet so far this is not always the case, as Slides 1 and 2 will show.

"The first slide shows the top view of a car. The second slide shows the rear view at the top from the old-style car and at the bottom from the new-style car. Clearly, we have a wider field of view with the new one; but on the other hand we have reduced the distance seen behind the car.

"It is however true to say, as does the Chief Inspector of Factories, that the initiative rests partly on the machine *users* to demand changes in the machine design. This does, however, lead to a rather circular deadlock at times. Here you have the dental story. In the supply of dental chair equipment, the users quite often say that there cannot be much



Slide 1. Plan view of private car.

(By courtesy of "Engineering")

wrong with the design of their equipment because they go to the very best firms. These same firms, however, say that there cannot be much wrong with their equipment because all the best dentists buy their equipment from them.

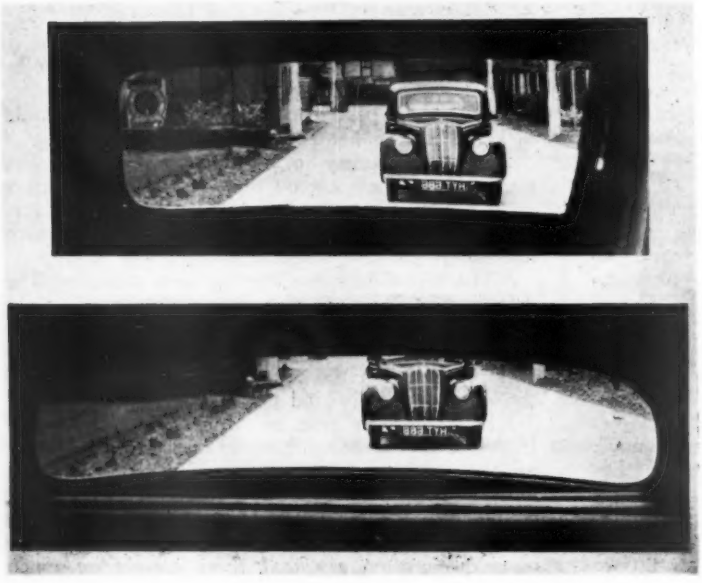
"Do not misunderstand me if at this stage I say suppose we now forget all about commonsense and get down to the scientific approach. Suppose we now consider our three other birds—(1) *inspection work;* (2) *decision taking;* and (3) *training for electrical maintenance.*

"But, first of all, why choose these three kinds of individual human activity, anyway? The general answer is that it seems to me that these are the three areas in which man plays a larger part than usual because, on the whole, it is here that automatic processes are rather less advanced.

"Let no one, however, underestimate the engineering achievements of the last few years. Slide 3, for instance, shows the sea of machines I was talking about. Given the correct input, these machines can take over manual work very effectively. But that is not, of course, the whole of the story nowadays. Given the correct input, machines can even take over *mental* work, such as translating from one language to another (Slide 4).

"Notice that I have said each time 'given the correct input'. For example, in the translating machine no device can as yet read from the printed page. Human effort must prepare a special input for the machine. Each time a punched tape representing the sentences to be translated must be specially made to provide the machine input.

"This can be regarded as a special instance of the general tendency for the sensing elements of automatic machines to be less far developed than other aspects of the equipment. Great advances are being made; but while these various sensing devices are being perfected, it is clear that for a time, at least, semi-automatic production is going to produce vast quantities of standard objects for *human inspection* rather than mechanical inspection. One machine can, for



Slide 2. Old *(above)* and new *(below)* rear windows of cars.

(By courtesy of "Engineering")

example, produce more than one million electric light bulbs a day. How much of the resulting inspection work could be done by machines, and how much has to be done by human inspection?

" It is, of course, to be expected that when someone works for a long spell at a difficult inspection job, they will begin to make more errors. Commonsense does not, however, say *when* that increase is going to occur. The need for exact measurement of the time of onset of this increase therefore becomes clear. The fact that a definite and important piling up of errors does occur under certain circumstances needs no emphasis (see Figs. 1-6 in the Paper).

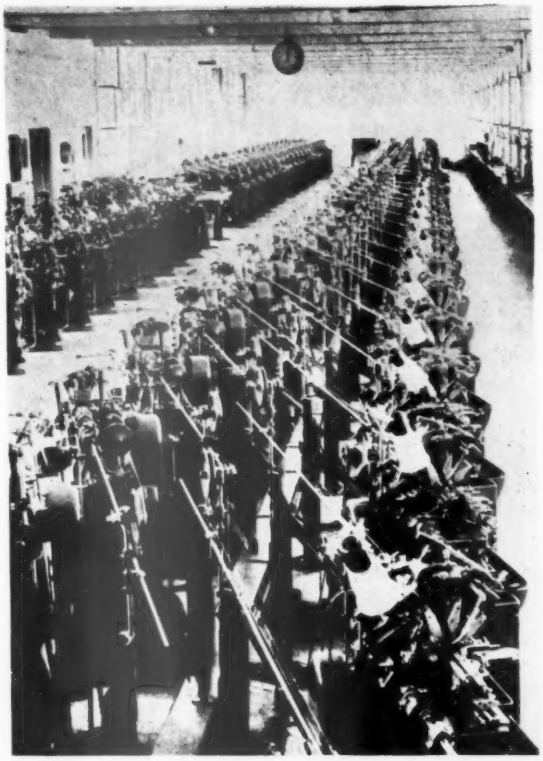
" We know that this is a real risk, and it is now important to try to define more exactly the conditions under which this change does occur and when it does not occur. This is more than just a matter of the visibility of the visual signals.

" For example, in the task itself one of the most important problems is to try to discover the minimum number of significant events per hour that people need to keep them alert. Another question is whether all these significant events have to be part of the real situation, or whether it is worth while adding simulated events to keep people awake, in case such additions have just as much alerting value as the real events.

" Another way of looking at this problem of the maintenance of effective alertness is to determine whether switching between two different inspection tasks at half-hour intervals, is perhaps, sufficient to keep up accuracy. It may be necessary to alternate inspection tasks with a non-exacting visual job, such as packing, but this is not yet known.

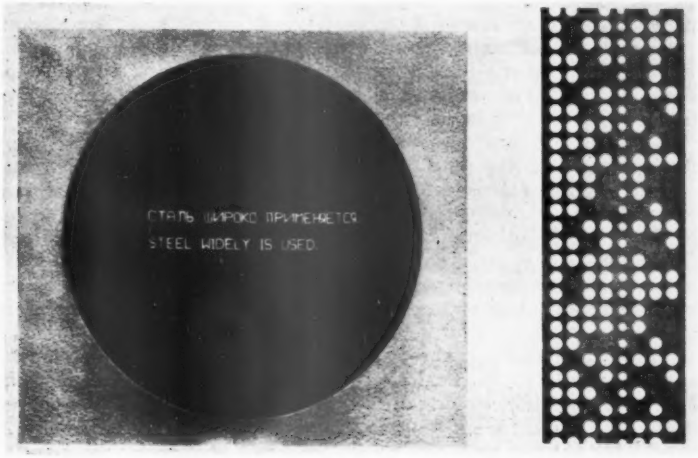
" A more important point is also mentioned in the Paper. This is the question of why people are more likely to show a performance decrement with a machine paced task than they would otherwise.

" Recent work has established that people will move about rather more and get increasingly restless during work of this kind. But no one knows whether people also let their gaze wander over a wider area as time goes on, and therefore do not see momentary critical



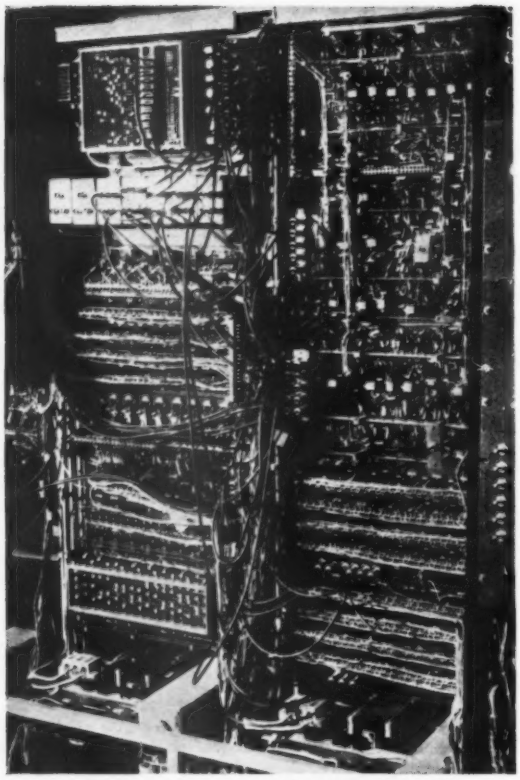
Slide. 3. An installation of 150 automatic lathes. *(From " The Robot Era ", by P. E. Cleator, by courtesy of the publishers, Messrs. Allen and Unwin, Ltd., and Usines Tornos, Italy.)*

events. Another possibility is that as time goes on the effective visual field of view becomes narrower and narrower. It may also well be that certain areas within the field of view are specially liable to show this decrement. There are no detectable changes in the eye muscles themselves, but nevertheless, in the



Slide 4. Machine translation.

(By courtesy of " Scientific American ")



Slide 5. The electronic computer unit.
(From "The Robot Era", by P. E. Cleator, by courtesy of the publishers, Messrs. Allen and Unwin, Ltd., and British Tabulating Machine Co. Ltd.)

long run, electro-physical studies of general bodily muscular tension and of electrical changes in the brain may greatly help towards an understanding of these events.

"Finally, there are signs that inspection work experiments may tell us more about the effect of temperamental differences between people on the types of work they can successfully undertake.

"These are the main reasons why I put inspection work so high on the list. It seems to have a great deal of scope for exact experimental study, and the findings may be both useful and interesting, especially if laboratory results are followed up by further measurements on the shop floor.

"In *decision taking* the problems are much less well defined, although in some ways they are becoming even more important than the inspection work. Obviously—as may come out in reading the Paper—to some extent the two forms of work overlap in the more complex forms of inspection work (see Figs. 7 and 10).

"More and more of these jobs are beginning to appear nowadays. Physical effort is at a minimum. Instead of one man looking after only one boiler, he may now be controlling four boilers from a central panel. He has lost his heavy handwheels, but he has also lost his bonus for physical effort. He obviously has more responsibility. But just how demanding is his job?

"What are the dimensions of difficulty in work of this kind? People are beginning to ask these questions—not only to determine rates of pay but also to decide when it is necessary to split up a job between two men. In fact, if we knew the main causes of difficulty in work of this kind, then perhaps we could help to design the work more effectively.

"The first way of assessing difficulty that springs to mind is perhaps the demanded speed of work—the number of decisions required per minute. Fig. 8 in the Paper is an example of the use of this measure within a given task. But in comparing one task with another this speed measure does not apply, because there is clearly the point that one hard problem, for instance, on a large electrical generator station panel may be much more exacting in a sense than several hundred minor adjustments in a boiler control room during the same length of shift. The electrical problem may never have occurred before, whereas the boiler room decisions are selected from about one hundred known possibilities. I think experimental work should perhaps start with the latter type of situation, where the thinking is really a matter of selecting one answer from a number of possible decisions, all of which are well-known to the operator.

"This leads on to the suggestion that another way of assessing the difficulty of a panel monitoring job is to consider the number of possible kinds of decisions in the task. Fig. 9 shows that under certain circumstances this can, of course, affect the performance. Having more decisions to choose from is particularly serious, naturally enough, when the demanded speed is excessive. A high average demanded speed is bound to be particularly harmful when there is a larger number of decisions to consider, especially when a high proportion of the information provided is irrelevant at the moment.

"Although many work design recommendations on decision taking tasks cannot be made at this stage, already some points are clear. There is the importance of avoiding irrelevant detail, including facts not needed at that particular stage. Secondly, there are the advantages of preventing two or more simultaneous demands for action. Thirdly, there are the benefits to be derived from displays which give the correct sequence in which decisions should be taken. To this I would add the type of quickened display suggested by Dr. Taylor with Dr. Birmingham (1954a and b).

"There are several ways of trying to establish the demands made by a particular form of panel monitoring. These would include recording of ability on the job itself, and before and after testing. But there may be something to be said for trying to add a second simulated task to the real job—to determine how much there was usually in hand, how much was usually left over from the real monitoring work. These two-task investigations might help to solve another fairly pressing problem. The high-grade people needed to take charge in such control rooms are often reluctant to take on this work because of the general

lack of activity. Perhaps we could find forms of work most suitable for the second task which could be introduced in reality to make this work more interesting.

"Now a word about *training for electrical maintenance*. Slide 5 shows the kind of twigs that our third dove has brought back. I think you will agree that if there are a few of these computers around, there may well be a maintenance problem, both for front-line and second-line maintenance.

"Do we know what the content of maintenance training courses should be? I suggest that work on the lines of that by Dale (1955) will help in this respect. Secondly, I suggest that new training schemes should be evaluated for their effectiveness in the ways outlined in the Paper. It may be that some of the ideas being put forward for training electrical maintenance men are better than others. This should be studied by investigations which will measure subsequent achievement and knowledge. The shortage of staff to train these men makes this perhaps even more important.

"Since electronic techniques change so rapidly, it will often be necessary to give a good basic understanding of electronics. The problem may then be to make the basic work sufficiently interesting. Perhaps this can be done, as suggested in the Paper, on the lines of the work of Johnson (1951), by practical constructional work closely uniting the mathematical and physical principles being taught.

"Electronics is not the only subject that is changing rapidly and, indeed, I would draw your attention to one point about the references at the end of the Paper. Every one of these has been published in the last five years. Applied experimental psychology is a fast-growing and rapidly changing subject. We want to be sure it is going in the right direction. In the discussion I hope we shall get some indication of your views on possible lines for further work."

DISCUSSION

Sir Frederic Bartlett (*Medical Research Council Applied Psychology Unit*) opening the discussion, said it could be argued that the best way of getting a reasonably good discussion was for the first speaker to disagree violently with the Author of the Paper. He personally, however, found it exceedingly difficult ever to disagree with Dr. Mackworth. On this particular occasion it was impossible, and he felt bound to agree with everything that had been said.

He proposed to comment on two questions raised in the Paper about which the Author had said a little more in his opening remarks: that of decision taking, and that of training.

Decision taking raised important questions partly because, as everybody was aware, there had lately been many movements in industry based on proposals to set up established differential rates of reward.

When people demanded the acceptance of a principle of differential reward, what they were usually maintaining was that the greater reward should go where the greater skill was demanded, or the greater responsibilities had to be met. The difference between skilled and routine performance was mainly due to the fact that, in any kind of skilled performance, decisions had to be made at key points. If those decisions were made correctly, all the minor adjustments required would be carried out without difficulty. If, however, decisions at the key points were wrong, hurried, or misdirected, then everything else would be likely to be made more difficult.

What kind of criteria could be used to determine where the greater skills in industry lay, or were going to lie in the near future? Some people said that the more complex the skill, the more big decisions had to be taken, the greater the liability to fatigue. If then we could find out how tired a man got after he had been doing a job for a certain length of time in certain known conditions, we might be able to say that where he became more tired there was the greatest amount of skill or decision taking, or something of that character. Unfortunately, although people had been trying to measure fatigue for many years, there was still no really good or widely accepted way of doing it that anybody had discovered.

This was not quite true when considering the fatigue which followed very heavy physical effort. It was possible more or less to get a pretty good measure of that. But when considering the kind of work that involved making serious decisions, on which a great many other important things depended, one found that there was no good way of measuring the fatigue involved. There were one or two indications, however, and it would be interesting if those who had the opportunity of observing what happened under actual factory conditions would see to what extent the indications that had come out in research were confirmed in practice.

Dr. Mackworth had shown a slide of a control room in which there were a large number of recording instruments. Any person in charge of this room would have to notice when and how the recorders were varying. If a recorder varied more or less than a certain amount usually something special had to be done. The operation depended upon the right taking of the right decisions at the right moment.

Experiments had often suggested that anybody who was observing instruments in this manner had what might be called an indifference range. He would allow the pointer or marker on an instrument to move a limited amount before he considered it necessary to do anything. As he got more tired, he would allow it to move a little more than he would at the beginning. But he did not know he was doing this; he thought he was doing just as well as at first. In fact, his indifference range was increasing. It might be that a measurement of the amount of fatigue produced by high-level decision-taking might be obtained in terms of the extension of indifference range.

Again, it might be that as automation increased, and decisions involving wider and wider ranges of activity became common, an effort would have to be made to build up a scale of the importance of operations in terms of the amount of responsibility which was involved.

Nobody, he believed, had tried so far seriously to treat the notion of responsibility in a quantitative manner, but he thought it could be done, and must be attempted. The skills required in industrial practice were changing all the time with technological developments. When a plea was made for the establishment of differential rewards, with the higher rewards for the more complex and difficult skills, traditional beliefs about industrial skills would have to be revised. One possibility might be to say: "Here is a set of operations in which, every now and then, some person has to make a key decision. If he decides wrongly, or times his decision wrongly, then the work of x number of people will be affected. Here is another man who has to make major decisions. If he goes wrong the work of $x + y$ other men will be affected." The second operation would be considered the more responsible one, in the sense that if a mistake were made it would involve far more people, or far greater expenditure in some other way.

Either in this manner or in some other, it seemed likely that industry would need some rough but practical scale of responsibility.

The problem of training in industry had become both different and very much more important in the last few years. The last industrial revolution was based mainly upon the

development of large-scale production methods, in which the work of individual operatives was reduced to as small a number as possible of routine movements. Industry was now moving towards a stage in which the main production work would be done by the machine. The human work would lie in devising, monitoring and maintaining the machine.

Routine repetitive work would probably be less common and less important. The industrial operative of the future might have to be trained to do many different things, and might have to be able to turn over from one thing to another without any difficulty.

This would make training more important and the methods of training different. One of the greatest difficulties facing any teacher was how to train a person to be adaptable. To produce efficiency in one operation was relatively easy; but very often the more efficient a man was in making, for example, a small number of routine movements, the less capable he was when the conditions of work were changed and he had to do something a little different.

A little was already known about the kinds of education that were required in order to facilitate what educationists called " transfer of training ". Transfer of training would be one of the real problems of the industry for the next few years, and he himself believed that the training required for the operative would be a training in adaptability—a training as a result of which it became possible for a man to use what he had learnt in one situation to help him to cope with a different one.

Dr. Mackworth, in reply to Sir Frederic Bartlett, said one illustration of adaptability on the maintenance side was whether it would be possible to have electrical and mechanical maintenance done by the same people. There seemed to be an occasional reference to this at the Margate Conference as rather a dream of the future.

Mr. L. R. Beesly (*Director of Engine Production, Ministry of Supply*) said that Dr. Mackworth's researches led him to suggest that the introduction of automatic processes for inspection and decision-taking would have greater significance in five or ten years' time. In the present unbalanced economy it could be wished that this time factor could be shortened. But due to the high first cost of all automatic methods, the inevitable inertia effect of existing production techniques and the national shortage of technical skill, this was clearly not possible.

The application to industrial enterprises of very varied sizes and complexity, manufacturing components also of very varied sizes and required in widely differing quantities, were further factors that — he would suggest — tend to delay the introduction of automatic inspection.

Nowhere was this more apparent than in the aircraft industry. Here the stultifying effect on production of the essential modifications and the proximity of production to development made the likelihood of extensive automation very improbable indeed.

If inspection could be regarded as essentially of two kinds — comparative and interpretative — it was clear that the former lent itself to the introduction of automatic control systems. The latter would, however, seem to a great extent to depend on human intelligence. Perhaps Dr. Mackworth would like to comment on the possibility of automatic monitoring devices ever being considered as a substitute for intelligence.

In his Paper he had referred to the aero engine field, and particularly to the cost of the product. A lot of that cost was concerned with compressor and turbine blades, and as the aero engine industry developed, there would be a tendency for powers to increase. This would result in greater accuracy, better surface finish and better materials being used. But the quantities being produced were seldom large enough to warrant the extensive use of automatic control devices. It was, in fact, difficult to foresee any revolutionary changes in the near future. For example, in the production of the large number of compressor and turbine blades in the gas turbine, in order to inspect the twist, straightness, the thickness of aerofoil and root, semi-automatic multi-station instruments of the Sigma type operated by unskilled female operatives were used. There seemed to be little sign of fatigue or reduction in the alertness of these people. For errors in contour of the blade optical equipment was used and the checking which was mainly done by semi-skilled operatives was very rapid — indeed, a matter of seconds only.

On the question of training, certain advantages could no doubt be gained by closer liaison between industry and the radar branches of the Services.

Mr. R. Harle (*Production Department, T.U.C.*) expressed appreciation of the opportunity to contribute to the discussion and congratulated Dr. Mackworth on its readability. He suspected that some psychologists might take this as a criticism but there was much to be said for presenting subjects without jargon, so that the ordinary layman could appreciate what had been said.

He could not agree more with Dr. Mackworth regarding the need to design work in a way suited to human ability. It had been said that the greatest discovery of the twentieth century was that workers were human. It was therefore a useful follow-on that some attention was being paid to human ability. Consideration had also, however, to be given to satisfaction. In commenting on industrial development, a union had said recently that a worker got much more satisfaction from making steel than from making dolls' eyes.

Workers were not always afraid of more difficult work. He did not think one should be too categorical in assuming that all work must have all fatigue taken out of it. Nor should it be assumed in this connection that all or even the majority of accidents were caused by physical tiredness. It seemed to him, in fact, that the designing of some work suited no doubt to human ability could cause mental tiredness.

He was very interested in Sir Frederic Bartlett's comments on the measurement of fatigue. Fatigue could not be defined, let alone measured. Trade unionists had been telling time study engineers this for a long time, because there was a tendency on their part to regard near allowances as though they had been established on scientifically proven formulae. Maybe it was not a bad thing that fatigue was difficult to measure, because it left the door open for collective bargaining.

It was possible to see in the design of work a challenge to the machine designer, the work study officer and the production engineer. It was his own belief that there was too great a tendency on the part of the technician and the expert in industry to organise work on the basis that everybody was 5 ft. 9 in. tall, sat comfortably in a standard type of seat, used identical equipment and materials with exactly the same digital dexterity and visual acumen, and so on. In point of fact, of course —and if he might say so Dr. Mackworth showed an awareness of this — there was not a single person on the shop floor who conformed to this statistical concept. No wonder there were teething troubles when organising conveyor systems or production layouts on the shop floor — it would be amazing if there were not.

In this connection useful work had been done by the National Institute of Industrial Psychology in the clothing industry in relation to the size of bundles and the pace at which work approached the individual. If people were different — and surely they were — there was a challenge in organising work in accordance with the peculiarities and idiosyncrasies of the individual instead of working on averages.

He would make this plea not only from a human point of view, but as much as anything from the economic view. If technicians insisted on not noticing these psychological barriers which came in at some stage, they would continue with the idea that the shorter the cycle, the greater the specialisation and the greater the efficiency. That could be developed so far but there was a limit ; it could lead to mental reaction and diminishing returns.

Another thing one had to be careful about in this respect was not to assume that work was a relationship entirely between the operative and his job. There were certain social aspects as well. These were accentuated when the work was of a humdrum routine or repetitive character. He could think of nothing worse in any factory than a highly repetitive job which was isolated as well. Social and group relationship considerations must increasingly enter into discussion on manning schedules.

The Paper rightly stressed the increasing importance of inspection. Not that there was very much new in inspection, he supposed, but it was becoming more specialised and more exacting. In modern industry faulty inspection could have very dire results.

From the workers' point of view, the experiments described in the Paper were invaluable in drawing attention to fatigue problems and responsibilities, and the need for care when discussing work-load assignments and manning schedules, and the fixing of prices for jobs. It was surely not difficult to appreciate the desire of trades unions to secure widespread dissemination of research results of this kind throughout industry.

Did anyone really doubt the correlation between the design of work and training ? Bad design surely could not do other than increase and complicate training requirements and procedures. And perhaps it limited the number of people able and willing to the work concerned.

Trades unions had always been aware of the importance of training and experience particularly in relation to quality and satisfaction, and with confidence and safety.

Dr. Mackworth suggested that training for the automation and electronic age should start at school. That, he believed, needed a lot more thought. For himself, he felt that training was mainly the responsibility of industry. He appreciated that there was room for various types of courses away from the job for the theoretical approach. But training should be done on the job, especially where scientific and technical changes were rapid. Otherwise, it might be that it would be the older people who were left stranded. As Mr. Fletcher said, it was not much good telling the machine minder, technologically displaced, that there were plenty of openings for draughtsmen and other technicians. How did he acquire those skills ?

The difficulty was that management might take the easy path and rely entirely on recruitment, leaving the human problem unsolved.

If it seemed as though he was going slightly off the Paper, it was because he wanted to stress the responsibility of industry in this matter. It was his feeling that if industry did not face up to its responsibility it could become a social and political problem.

The wide divergences of skill practised by the machine minder, the technician and the maintenance engineer brought one back, he believed, to the need for designing work in accordance with the skill resources and potential, bearing in mind always that skills could be improved with training.

He had been very interested to read of the training experiments in the United States Navy and the difference between the experimental method and the usual method. He had learned during his apprenticeship in industry in spite of everyone, rather than because of everyone. The position was much better now, but certainly there was plenty of room for improvement. Industry should pay continuing attention to experiments of this kind and become familiar with them and with the results described in the Paper.

He had noted the comment by Sir Frederic Bartlett that it might be desirable for people to be trained in many jobs rather than concentrate or specialise on one. That might be a way of approaching the problem ; on the other hand, there was something to be said for regarding training as a continuous process, so that although a particular skill might become obsolete, there were available immediately (or preferably beforehand) training facilities to enable people to move to new jobs. The training process should go on all the time rather than there being a once-for-all training at an early stage. This was the tendency in many apprenticeships; after five years it was assumed that a man could tackle any new job or development that occurred in his industry or trade. It was a measure of the adaptability of the British worker that he got along so well, but a lot more could be done, perhaps by refresher courses or other means.

The question had been asked, " What was skill ? " How was it that one man worked more easily with much less fatigue than another and produced more ? This was happening in many factories and created problems for the trades unions because it lead to differentials, not wage *rate* differentials but *earnings* differentials.

The Boot and Shoe Research Association had been doing some work on this problem to find what were the respective skills of people within the same grade. This research was supported by the National Union of Boot and Shoe Operatives, in the belief that if such skill could be analysed it might be possible to devise training procedures to help the less efficient and help reduce differentials and, of course, the friction which sometimes existed among workpeople.

Mr. Harle considered that the Paper was a most useful one. The danger was that people would say there was nothing in it that they did not know — a remark often made with regard to psychology which was, of course, often an excuse for doing nothing. That commonsense needed to be applied as well as possessed could be proved in any factory. He had been in many establishments where they had not yet designed operatives to carry out some of the jobs ; the pity of it was the jobs did get done somehow !

He would conclude by quoting from the 1953 Annual Report of the Chief Inspector of Factories :

> " A 17-year-old girl received severe lacerations to three fingers of her left hand when her hand slipped on to the cutters of a knife-handle shaping machine. She was in the act of stopping the machine. Not only were the electrical gear of the machine and the guard for the cutters defective, but investigation showed that she had only received half-an-hour's tuition on the machine from the chargehand, who was a deaf mute."*

Dr. Mackworth said he would be interested to know, in connection with the previous speaker's remarks, whether people agreed with him that perhaps these monitoring jobs brought out some of the greatest differences between people. Experience in the laboratory certainly showed that individual differences in ability and in general behaviour were very marked indeed ; even within selected groups of people one man differing greatly from another. Did this also happen very frequently in the industrial setting ?

Secondly, he very much appreciated the forward-looking view that people did not always want to take the easier form of work ; because clearly in these monitoring jobs that was what seemed to be happening. People were turning jobs down because there was not enough to do. If it was going to be suggested that a second parallel task might at times be feasible, it was useful to know that the trades unions view was that this would be welcomed.

Dr. Franklin Taylor said he would like to expand a little on Dr. Mackworth's point that great gains could be achieved through simplifying the operator's task, and to suggest some gains that had not been mentioned.

At the Naval Research Laboratory in Washington, some work had been done on redesigning machinery to fit the man. The aim was to reduce the complexity of the mental operation in the computation. They worked with vehicles such as submarines, aircraft and the like, and pilot and control operations. By certain techniques to which fancy names were given, such as quickening, which consisted in the use of proper equalisation networks and servo designs aimed again at making the equation simple, operations were pushed down to the point where a man was doing nothing more than amplifying — acting as a straight amplifier. Considerable improvement in performance was achieved in this way.

With one particular device which he could not describe because it was classified, the operator normally took three weeks to learn the task and used a trainer which cost fifty to sixty thousand dollars. With the aid of this general principle of quickening, they had reduced the task, given the operator a new display and then found that absolutely no training was required. Literally, it took no longer now to train the man than to instruct him in what to do. A number of different subjects were tested, and all of them were able to do it. This was a very dramatic case. It could not be taken to mean that the same thing could be done everywhere in all problems. But in this one case it was possible to get rid of the training problem and of the selection problem and to make the man/machine system extremely precise. It was done by one of the very means mentioned in the Paper — simplifying the operator's task.

Principal Old (*Wolverhampton and Staffordshire Technical College*) said that as an engineer he had found Dr. Mackworth's approach most refreshing. Engineers tended to think that because they themselves had suffered from some sort of apprenticeship they were therefore the only experts in the matter. It was clear from what had been said that evening that they knew only a portion of the operation and that other people knew quite a lot!

He felt sure that in the industry of the future it would be necessary to train and retrain and train again. This would be inevitable. But he hoped that somewhere in the first period of training something which was fundamental would be provided, something which could form the basis of future retraining.

He was reminded of what he saw in Germany a few months ago, where vocational training systems were very much more specialised than in this country. There were, in fact, 600 occupations for which there were apprenticeships, and each of these was completely scheduled in the sense that the apprentice had to pass through a whole series of specific operations before he could be considered trained. At the end of the period, which was not five years but three to three-and-a-half, he was given a test. If he passed he was a craftsman. If he did not pass he was not a craftsman. But during the three to three-and-a-half years he was entirely under the training process. He did not learn in spite of the system, as did some people in this country in their apprenticeship days. So often, in Britain, an apprentice picked up what he could from the skilled men around him. The German apprentice, on the other hand, went right through the training schedule and the whole period was one of training, with no production work whatsoever.

The first step to achieving a similar result in Britain was job specification, and on the industrial side it was important to decide what one wanted the apprentice to learn. The next step was to devise means of producing the kind of skill that was required.

With regard to training in the U.S. naval yards, the system of mixing practical and theoretical work was not new. He must confess, however, that he was surprised at the quality of the results shown. He hoped they could be taken as genuine — and that they had been well authenticated. Again, if he might refer to the German system, they were mixing their theory and practice very intimately. If one imagined a small theatre seating about fifty people rather than the number in the present lecture theatre, there was a rotatable turntable where the lecturer's desk was about ten feet in diameter, and the fifty odd seats were filled with apprentices looking down on the turntable on which a machine tool could be operated. The machine shop was adjacent and machine tools could be wheeled in and put on the rotatable turntable. It was easy to see the advantages.

The Germans were certainly turning out craftsmen and it was because they were looking into the matter thoroughly and mixing theory and practice. The report on the U.S.A. naval work had therefore interested him very much because it reminded him of what he had seen in Germany, and he thought the two were on somewhat parallel lines.

At the end of the Paper, Dr. Mackworth got down to the matter when he said training must start in the schools. He himself felt quite sure that one should never try to teach automation or what it meant in the schools, and he did not think Dr. Mackworth meant that at all. But it was very important that those who were responsible for teaching in the schools should have their thinking orientated in the right direction.

In the grammar schools the average member of staff tended to think in terms of a future profession for his boys in law or medicine or pure science, and, of course, in teaching. This tended to condition the thinking of his pupils. What was wanted was some other kind of school, and he personally would like to see far more Technical High Schools where the subjects taught might be similar to those in a Grammar School, but taught with a rather different slant. There were some people who tended to confuse the real purpose of education, which was not to teach a subject so much as to develop attitudes and to orientate the thinking of the pupils. This was perhaps what Dr. Mackworth had in mind and he was completely with him in that.

Mr. B. G. L. Jackman (*Vice-Chairman, Research Committee of the Institution*) said that Principal Old had stolen most of his thunder and there was little he could add. The point he had intended to take up was the suggestion, or implied suggestion, in the Paper that specialised vocational training should start in the elementary school before the age of fifteen. He disagreed fundamentally with that, although he was aware that the Chairman disagreed with him about it. He himself thought boys of twelve to fifteen were still very young, and whilst it was good for them to make models of aircraft and ships and so on as a hobby, it was not right to push them into fairly complex manual training and a certain degree of theoretical training at that age.

In this connection, he had looked up a passage in a recent publication many of those present would know — a publication issued by the Birmingham Productivity Association, called "Gaining Skill". The Association had recently sent a team to Germany to study the training of apprentices, and one might almost think Principal Old was a member of that team, though in fact he was not. He himself made no excuse for quoting the very apt comments on this particular point, and he hoped he would be forgiven if the meeting was having too much of Germany at one time. In addressing the team, Dr. Grünther, Head of the Department of Vocational Training in the Chamber of Industry and Commerce, Frankfurt, said of the English system that training in factories as well as in schools depends on the principle of selecting appropriately qualified juveniles. This, of course, meant that only a small number of the juveniles entering industry in each year had a chance of special training in their factories ; whilst since attendance was not compulsory there was no nation-wide use of vocational training schools. In Germany a different system operated. The kernel of vocational education was a universally recognised period of training for all school leavers entering industrial life. This period of training was observed by all branches of industry, trade and commerce. The parents, the children and the firms regarded this period of apprenticeship, which lasted on an average for three years, as the traditional foundation for acquiring ultimate skill. It was considered a matter of honour to become a skilled man, and this accounted for the readiness with which a contract of apprenticeship was entered into. The apprentice willingly agreed to being bound to one firm with but little financial return for the period of his training in the faith that it would pay off later both socially and economically.

This sort of vocational training set-up was required at the age of 16 to 18 and not back at the elementary school, and he thought one would like to see it in this country.

With regard to measuring fatigue, one might well put at the top of the scale as a measurement example — and Mr. Harle would appreciate this — those industrialists who argued for two or three hours with a group of shop stewards who were hammering a particular point. That task was certainly not monotonous, nor in any way repetitive, but it was very necessary and very fatiguing.

Dr. Mackworth said he thought he should clear up a misunderstanding about vocational training. What he meant was that a small amount of time should be devoted to this, not the dreadful suggestion that the whole of the training should be vocational. Perhaps a few hours a month should be given to opportunities for becoming familiar with electrical engineering problems by building simple electrical equipment, even at an early age.

Mr. J. V. Connolly (*Director, Sundridge Park Management Centre*) asked whether Dr. Mackworth had any figures showing the amount of work he and his colleagues were doing in Britain compared with the amount of similar work which had been done across the Atlantic, in all the institutions similar to that of Dr. Taylor of the U.S. Navy Psychology Unit.

From the implications of the problem of designing the new automatic equipment and inspection methods, it would seem that the few people capable of carrying out this work in Britain were going to be rather fatigued and certainly flooded out with demands for advice.

To train a man to do constructive work in this field was

not just a question of developing simple formulae and eliminating all the skill. This was a very ill-developed part of the subject, as Dr. Mackworth had indicated. It was still a bit intuitive and it required a sound training in the sciences, physics and possibly even chemistry, and then in logic. It meant a good deal more in mathematical techniques so that he could distinguish statistically fine differences between one fact and another. One would not get all that in any man under about 25 to 35. If these people did not come along for constructive work, the position would be very dangerous. Dr. Mackworth might like to consider what was the possibility of doing something fairly rapidly in this matter ?

It might be a mistake to worry too much about inspection in connection with automation. Automation by its very nature meant that one knew *how* to do the job and knew a good deal about it. It was comparatively easy to build in at any stage of automation a similarly good automatic inspection system, so that not a great deal of inspection was necessary. This did not necessarily apply to monitoring, but it would seem that even here machinery could probably do the monitoring without any serious " indifference period " as compared with the human being. It might be that the conception of automation was not being carried far enough if anyone was worried about the inspection aspect.
(*Added in writing*)

In the field of work under discussion, the main advantage of a human agency was that it could work from partial information. Any *machine* must work according to rule — the rules may be completely known and then the machine will probably be faster and more reliable than any man. If there were many exceptions the programme set to the machine has to go through many cycles to compare the alternative answers with some standard of judgment, also built into the machine. In most cases a suitable human link can cut across this lengthy process and give a correct answer by using (possibly) " commonsense " or experience of previous analogous situations.

Dr. Mackworth said it was very difficult to compare the amount of work being done in Britain and the United States. At a guess he would say that the whole of the work of this type which was being done in Britain was equivalent to the effort available in the United States for the U.S. Navy.

He agreed with Mr. Connolly that the inspection of work problem was a temporary one. The rate of change of technical innovation was very difficult to estimate. But perhaps for the next five to ten years it would be extremely difficult, for example, to detect small particles of glass in ampoules by automatic processes. Though great advances were being made in sensing devices, there was some lagging behind, so perhaps this problem would arise for the next five to ten years.

Mr. R. B. Kemball-Cook (*Production Engineering, Limited*) observed that Dr. Mackworth had not found time to mention one solution he had suggested in his very stimulating Paper to the problem of the modern citizen in deciding whether to look at the B.B.C. or I.T.A. Up to November last year the listener could quite happily sit down in his chair in the evening and switch on the B.B.C. and any other mental life for the rest of the evening could be neglected. Now he was faced with this appalling decision and the incidence of neuroses in London suburbs had gone up strikingly. The excellent suggestion that there should be two television sets side by side had presumably solved the problem !

More seriously, he would be interested to know whether some of the short-time experiments mentioned in the Paper on the increase in error on making decisions gave sufficient allowance for the adaptation of the human being to the demands which a difficult task made on him.

Figs. 1 and 2 described experiments lasting roughly two hours and showed the increase in errors. He himself had an uneasy feeling that if one put an operator in the driving seat of a car and showed him all the controls and let him try to drive the car for two hours, one could prove that it was not possible to drive a modern car in traffic at all. Even to turn a right-angle corner in a car one had simultaneously to work the right foot on the accelerator to within a fraction of an inch ; the left foot on the clutch with considerable precision in time and space ; the left hand on the gear, again, with exactly the right timing ; and the right hand on the steering wheel with considerable precision. By such experiments one might prove it was not possible to drive a modern car. Yet the late Johnny Claes, the Belgian driver, was able to drive for fifty-two hours in the Liège-Rome Rally without making any errors serious enough to result in a disaster.

There were many operations in industry in which the operator had to adapt himself, and it was his brain and nervous system that did the adapting. A complete input and output system might be developed but it might take several weeks or even several years to do that. The results might be very different from those that would be expected from short-time experiments. He believed Dr. Mackworth's research unit had devoted a great deal of attention to these problems, but perhaps this was not brought out in the Paper.

Dr. Mackworth said that he and his colleagues would very much welcome greater opportunities of matching laboratory-type results with the real-life situation evidence. One could say that the laboratory evidence in Figs. 4, 5 and 6 did tie up exactly with the operational evidence. The rate at which accuracy fell off in the real watchkeeping job was the same as in the laboratory — perhaps by chance, but it was the same.

Mr. E. Gordon England said it was not in any sense out of disrespect for Dr. Mackworth that he would like to invert the Paper and start at the end. Dr. Mackworth had summed up the whole situation very well in his paragraphs on education. He himself entirely supported the view that one could not start too young in educating people.

If he had understood Dr. Mackworth's Paper correctly, its theme foreshadowed the coming eclipse of specialisation. He hoped the Author would comment on that conclusion, and also upon the idea that what we were witnessing was the development of a new phase in human affairs that must be faced.

It was terribly important to start with the young at the present time. Young people who should be learning how to think, were being taught to concentrate their attention and efforts upon specialisation.

Dr. Mackworth's Paper would, he thought, be an epic in the history of the proceedings of the Institution. It was full of entrancing avenues, up which one might be tempted to explore. There were so many of them that one had to be very careful not to get lost, but each was of great importance in the coming changes in the whole industrial situation. Each one of these avenues would be found later to become increasingly important and its exploration would suggest a new line of development in the field of production engineering.

He was particularly interested in Dr. Mackworth's point about the value of change of occupation. This innovation had to come. A few years ago he had carried out some experiments — to be frank he had been forced by circumstances and conditions to carry them out — in reducing the working hours on certain jobs to as low a factor as two hours per day. He would not bore his audience with the details, but he was putting the case forward because it supported Dr. Mackworth's thesis.

When the working hours had been reduced to two hours per day on a certain job, it was found to give the best result and, consequently, each operative had about six spare hours. It was then decided to divide a number of jobs into two-hour spells. In other words, every day each operative did four separate tasks of two hours each. The increase in output was phenomenal both in quality and quantity. Far more important, in his opinion, was the fact that the operatives said that they had discovered at the end of the day they went home looking foward to coming to work on the following day, whereas previously they had rather dreaded the return to work. He felt sure that the report of the result of that experiment would be close to Dr. Mackworth's heart.

He rejoiced in the fact that the Institution had had such a human Paper presented to it.

The Chairman had said that of course the production

engineer was wholly concerned with human affairs. He himself only wished that that was the truth, for if it were they would be much further on in their endeavour to attain greater productivity.

There was one question he hoped Dr. Mackworth would answer quite frankly. Was he entitled to detect in the Paper the advocacy of an escape from responsibility, or had he misunderstood and was Dr. Mackworth advocating more responsibility? He was not sure whether the thesis was clear on this point. He suggested to Dr. Mackworth that one would only increase human happiness and bring about better conditions in industry by increasing the responsibility factor in everything human beings did.

Dr. Conrad (*Medical Research Council Applied Psychology Unit*) said that Dr. Mackworth had stressed the importance of measurement in the study of behaviour. It seemed to him that the concept of measurement had a somewhat special significance in the field of work design. This field was typified by the situation in which there was a man and a machine, or a man and several machines, or a man and some mechanical or electro-mechanical system. The man had to be taken more or less from stock so to speak, but the machine or other system was designed.

In this design, consideration might have to be given to how many machines one man could cope with, or how fast a machine should be run, or how many men would be required to deal with the output of the system at a particular point — and so on.

In recent years, applied statistics had provided many tools which had made these estimates matters of exact calculation. Now, in the mathematical solution to a good many bio-mechanical problems, there needed to be some function which represented the behaviour of the man, and quite often the human operator was assumed to function like a switch, in the sense of having an operating time of constant duration. But, of course, he never did function in that way. Alternatively, for mathematical convenience, his response time was assumed to have an exponential distribution, and this was not true.

Two main sources contributed to the variability of human response. Firstly, there was the innately variable response of all biological organisms to repeated identical stimuli. No single distribution of response time or operating time had ever been calculated which would fit all of the different cases. It was not a normal distribution, nor was it log normal — though many had hoped that it might be as simple as that. For what it was worth, more recently, the flexible type-3 Pearson distribution had been suggested, and still awaited confirmation or rejection. In any event, this was not just a finicky academic point. It was the difference between having a blunt tool and a sharp one.

That was the first main source of variation of human response. The second main source was to be found outside the organism and was a function of the particular operating conditions. Of course it was known that many conditions would disturb this function, and Dr. Conrad merely wanted to draw attention to one which was both important in work design and had also tended to be neglected in the past.

They could, for instance, set up in the laboratory, a task which was an analogue of a typical simple queueing situation. They could arrange for the random arrival of "customers" in the form of electro-mechanical events, arriving at a controlled average rate. A customer arriving whilst another customer was being dealt with, did not get served. But in the laboratory case, they had a human being servicing the customers, and his service time was not constant. Now when the mean arrival rate of customers was systematically increased, it was found that the proportion not getting served became increasingly greater than it would be *if* service time *were* constant. They needed to write into the equation a service time which was itself a function of the customers' arrival rate, in order to match the observed facts. And this would almost always have to be done wherever servicing was done by a human operator instead of by an automatic device.

Perhaps he might give one more rather more practical example drawn from some recent work he had been doing, of the importance of bio-statistics in work design. One of the criteria of efficiency of a telephone exchange was the interval between the time of arrival of a signal at the exchange, and the time when an operator answered it by plugging in and saying "Number, please". This interval was known as the time to answer. The duration of the time to answer clearly depended principally on the density of traffic—other things, including the number of operators, being constant.

If the operators behaved like automatic devices, decreasing the traffic would lead to a decrease in the average time to answer, which would fall until it nearly reached zero with very light traffic. With human telephonists though, there was a different picture. The first part of the relationship was the expected, but if the traffic became very light (relatively), the time to answer tended to begin to rise again, so as to give a U-shaped function. To calculate, therefore, what would actually happen in the Exchange, in order for example, to determine staffing schedules, a function was required which really *described* the behaviour of the people, and did not merely treat it as switchlike.

The unique feature of this particular aspect of human behaviour was that it represented adaptation not to the physical appearance of equipment, nor to the climatic conditions in which work was carried out, but to characteristics of the work situation which had a determinable statistical structure which was usually of a fairly simple kind. What was generally lacking in the picture was an equivalent determination of the un-switchlike human response. Furthermore, behaviour was perhaps more variable with respect to this particular feature of the total work situation when it was present, than to any other.

Dr. Conrad suggested, therefore, that no programme of work design could be complete without the use of applied *bio*-statistics, and he thought that Dr. Mackworth had shown admirably from where, and how, these bio-functions were to be obtained and extended.

Mr. D. Braid (*Masson Scott & Co. Ltd.*) emphasised the importance of training the future craftsmen. There was no doubt, he said, that electronic craftsmen would be badly needed in the future together with the mechanics to build and maintain the latest equipment used in modern factories.

He agreed with Dr. Mackworth—and therefore disagreed with most of the other speakers—that many basic skills could be discovered in the younger generation at a very early stage. Where they had opportunities in their home life, skills were developed to the fullest extent, but many would not have any facilities outside of the short period at school, thereby being lost as potential craftsmen. It was therefore necessary to provide additional training opportunities to discover and encourage basic skills which could be channelled into vocational training for industry at the age of fifteen.

The only point on which he disagreed with Dr. Mackworth was whether it should be a Government responsibility. With the increasing technical complexity and the mechanical requirements of life, not only in industry but as a whole, everyone could benefit from some such basic training—if it was only to be able to do a simple electrical job or maintain a motor car. Therefore, no one would lack any basic advantages if he got some of this preliminary training while at school. It was a national responsibility to increase the supply of craftsmen and instead of following the historical precedent of being last in the field, we should be far in advance of other nations, taking steps to do so at the earliest possible stage. This should be emphasised to politicians and educationalists and their very definite support was needed.

Mr. M. Seaman (*Chairman, Editorial Committee of the Institution*) said it would be a pity on the occasion of a Paper which broke new ground, not to make a comment which would widen the scope and perspective of the Paper as a whole.

In thinking of the perspective that was opened at the conference on automation, one was struck by the very great opportunity for what might be called "overhead skills". At this stage he had in mind particularly the title of the Paper: "Work Design and Training for Future Industrial Skills".

One tended to think about the ultimate manual skill that came into some automatic or monitoring operation. Was it not very significant, for instance, in automatic or computer

control, that the very terms of reference of accuracy and skills were completely reorientated? The draughtsman started off to measure from two or three axes of reference his major accuracies and proceeded to reduce the variations in rate fixing and planning and machine estimation, finishing control by the very act of computation in the whole series; so that what, in fact, one got, was the designer designing the two axes of reference, using a system of skills to put the exact top quality skill in the machine either in a two-plane or a three-plane machine. A whole number of skills "went by the board" for ever at the moment that that concept came to fruition.

Dr. Taylor, in mentioning the work of the United States in the reduction of training time, was on to a very important point: that in effect as one found in gun computer control some system of fatigueless reduction of error, skill was concentrated into very special categories.

His only purpose in widening the discussion still further was that it would be a pity, in such a signal and far-reaching piece of work, if the Institution in its writings and counsels failed to appreciate that what was under review was the whole level of overhead skills—engineering, planning, rate fixing and processes of that type as well as the processes of sheer dexterity.

If he might suggest a definition of skill, it was the successful attempt not to have to make a decision!

Mr. K. J. Hume (*Chairman, Papers Committee of the Institution*), in moving a vote of thanks to Dr. Mackworth, said that the nation-wide discussions on automation that arose from the Margate Conference—which at least triggered them off—included a fair number of references to human problems. Thought at that time, however, was concerned more particularly with the idea of redundancy and with the very real problem of the use of leisure. Less thought was given to some of the more complex human problems relating to the actual work that would have to be undertaken at various levels. It was in this field that Dr. Mackworth had given such an excellent review of the work that had been started and would obviously have to be continued on a much greater scale.

It had for a long time been fashionable to scoff at attempts to measure human abilities, witness the fun and indignation aroused by various types of intelligence tests. And yet compared with mechanical measurements attempts to measure human beings were still very inadequate. Many people thought attempts at mechanical measurement were still inadequate. Fatigue had received much attention in the last few years, for instance; and yet little was known about it. How much less was known of the human factors in fatigue! How little was known about all the complexities that had to be analysed!

Much greater attention would obviously have to be paid to the selection, training and opportunities for practice of personnel concerned with the various functions in the automatic age. Whilst he agreed with some speakers that there must be a review of ordinary training and education in the schools at all levels, he thought there must be some rethinking as to what education meant. Some of the classical ideas about general education which had been satisfactory in the past were not necessarily the only ideas that would be satisfactory in the future. This was not to say that more specialisation should be introduced or that too much engineering should be introduced into the ordinary school curriculum. Education should be on broad lines, but thought must be devoted to what education was eventually going to do for the people who were being educated.

There was one practical point relating to a basic understanding of electronics. Many people would agree that for anyone who was to be an engineer of whatever sort, whether an electrical, mechanical or production engineer, the time had come when he must have at least a working knowledge of electronics. Electronics entered into every phase of life and it would do so more and more in the future.

The Paper had been most stimulating and the discussion had ranged over a wide field. Great interest had, he thought, been aroused in the Institution and its effects would be felt over an even wider field. It gave him great pleasure to propose a very hearty vote of thanks to Dr. Mackworth for his excellent Paper.

The vote of thanks was carried by acclamation.

Communications:

The following written comment on the Paper was received after the meeting:

From: **Mr. G. M. E. Williams,**
(*Combined Technical Services, Ltd.*)

1. The Author has remarked in his Paper upon the obvious nature and the simplicity of the ideas in it. Many of the conditions described are of the kind which produces the instinctive "He's tired, you know", heard often after the failings of any human being since birth. The importance of the Paper is that it brings together much measured data. These enable reinforcement of decisions on methods of limiting the effects of failing powers of human beings connected with various changing factors.

2. It is suggested that it is unfortunate that the Author uses the term "electronic brain". Even the use of the singular of the word "brain" is questionable, as automatic computing engines are, in design, the products of several human brains. They are used by other human beings, whose brains either make incomplete, or sometimes greater, use of a proportion of the combined brain (if such a term is admissible) of the designers.

None of these machines will think in the manner, not easily defined, which has brought mankind to his present supremacy.

Automatic computing engines will conduct only those thought processes which their designers and users have built into them, and instructed them to use. They will conduct these processes much more rapidly and extensively than human beings can in a given interval of time; this is the fundamental reason for their development. But automatic computing engines are in nature no more "brains" than a slide-rule or desk calculator. Speed, capacity and range of mathematical operations are the factors which are different.

This point has been somewhat laboured because the Author qualifies Hooper* and goes on to mention the use of machine prediction in servo-systems—presumably lag-compensation by pre-correction. Whilst undoubtedly the development of control systems will take over more and more of the human controller's functions, there is a possibility of a feeling that is not desirable being engendered by the Author's qualification.

3. The important point has been made by the Author that the uses, including the detail and form of the output of a computer for management studies and control, need very careful study. He suggests a method of "paring away the material until comprehension began to fail". This surely needs qualifying by adding that there are certain indispensable items of information, e.g., the state of financial solvency, which may not be comprehensible but are certainly vital.

4. On the measurement of fault location, the approach might more usefully be made from another direction.

It is frequently unavoidable, for instance, in the Armed Services, that men with inadequate knowledge must be used for maintenance work.

Let us assume that the men available are so poorly equipped with knowledge that they know nothing of their intended duties, and that they are therefore chosen at random. Given a maintenance job to do with a minimum of training, the poorest specimens will choose random methods to find faults, they will guess. These represent the bottom of the scale, and it is based upon this quality of man that the Author appears to have approached the problem.

At the other end of the scale, the designer-builder of an equipment knows most about it, and it is common knowledge that he can, in general, detect, identify and cure faults in his equipment more quickly than any other person. The important feature of his knowledge is that he is armed with knowing the logic of his equipment, the flow-diagram of events within it, and this knowledge is essential in tracing faults.

It is felt that the approach to the problem which would be perhaps more fruitful, would be by investigating, from the designer's level of knowledge downwards, what can be pared away, in the sense referred to in 4 above. Con-

* "The Automatic Factory—What Does it Mean?" I.Prod.E. 1955 page 138.

sideration could then be given to finding the minimum number of levels of maintenance and of men per equipment needed in them. This would have repercussions on the general systematic design of any equipment, which should thus be viewed with maintenance needs as a part of the whole conception.

From: **Mr. M. Zvegintzov,**
(*National Research Development Corporation, Ltd.*)

The really difficult problem will be the training for new skills of individuals who are no longer very young. They may be highly expert and in positions of responsibility for their own skill when the pace of technological progress and change overtakes them.

Dr. Mackworth made the point about electrical maintenance and showed a slide of a machine whose circuits looked like a ball of wool after a litter of kittens had been playing with it. I wonder if simplification of design may not be the best way of meeting the increasing difficulty of training skilled maintenance personnel? Dr. Mackworth has probably seen the details of construction of the latest Elliot and Ferranti computers, which are based on a multiplicity of small standard packaged units, any one of which going wrong can immediately be pulled out and replaced by another standard unit from stock—thus allowing the particular faulty element to be located and repaired or replaced at leisure. The printed circuit technique is another big step forward in simplifying and standardising circuitry, thus making replacement of anything faulty quite easy. (Incidentally, the production and assembly of printed circuits lends itself particularly well to "automation").

I was somewhat surprised by the doubt cast by one or two people (including Mr. Harle) on the reality of "fatigue": I should have thought this state—which might be psychological—is a very real one. I personally know how "tiring" it is to watch intently for something that you know hardly ever happens, in order to detect in time when it does happen. This sort of strain is, I gather, in quite a number of cases further intensified by a feeling of loneliness—a sort of "light-house keeper" atmosphere. (As a result, oil and chemical companies on some of their continuously running highly automatic processes always have two people on or around the control panel, even though strictly speaking one would be enough.)

"SOME ASPECTS OF AUTOMATION IN THE TEXTILE INDUSTRY"

(concluded from page 213)

(since it partly obscures the light falling on to the mirror and the light reflected back to the cell), and consequently the control potential developed by the cell. Any change in this control potential is transferred to the amplifier resulting in a flow of current in the field winding of the motor unit, thereby controlling its torque and direction of rotation ; 85% full torque is obtained by a deviation of 0.04V from standard.

The guider arm, which is geared to the motor shaft, changes its angular position to that of the approach of the cloth, resulting in a return to the original cell coverage and a state of electrical balance of the system (i.e., zero motor torque). This ensures that the cloth selvedge is fed to the cloth guider wheel in a definite position relative to the edge of the wheel. The cloth is drawn off the guider wheel by the overfeed wheel pins, or by clips *via* a transfer wheel along a fixed line which is an extension of the axis of rotation of the guider arm, and is then in the correct alignment for pinning on the stenter, irrespective of the original angle of approach of the cloth selvedge.

To prevent "hunting" or unwanted oscillation, due to the extremely rapid speed of correction, a damping or anti-hunting circuit is incorporated, utilising the voltage derived from the generator portion of the motor generator unit as velocity feedback. This has the effect of allowing the guider arm to move as rapidly as possible for any given correction without overshooting its correct position.

Automatic Weft Straightening

As the cloth is fed on to the pins of the stenter *via* the overfeed wheel, ripples are formed across the cloth. These ripples will be perpendicular to the selvedge if both ends of the same weft thread are fed on to the pins at the same time. If, on the other hand, a weft thread is fed on to the pins at one side of the stenter before the other, the ripples will follow the line of the weft. This property is used in the automatic weft straightening device. A light source is directed on to the ripples, where it is reflected on to two photo-electric cells one at each side of the machine, and the output from each cell is used to control the speed of the appropriate stenter chain. If the overfeed becomes excessive at one side of the stenter, unequal amounts of light fall on to the two cells and the speeds are adjusted until a balance is restored.

Although the various automatic control devices have been described separately, there are many instances where they are the integral parts of a continuous process. The crease-resisting process is perhaps the best example. The cloth in open width passes over suitable tension controls, through the impregnating bath, over heated tins and is coupled to the stenter with a compensator. The stenter may be fitted with photo-electric selvedge guides and automatic weft straighteners. After leaving the stenter, the cloth passes over a second compensator thence to the baker where the final curing of the resin takes place.

Conclusions

Considerable progress has been made in the application of automation to the textile industry, but its large scale adoption by the industry has been slow. This Paper has attempted to emphasise some of the work that has been done, but does not pretend to be a complete survey. For example, it has not covered important developments in warp and weft knitting, carpet marking, or the synthetic fibre industry. A brief description has been given of how the growth of the industry since the days of the Industrial Revolution, combined with the variable nature of the raw material that has to be used, has been a deterrent to the introduction of fully automatic machinery.

Acknowledgments

The Author would like to acknowledge the generous assistance he has received from various machinery makers and for the loan of photographs. Special thanks are due to the British Northrop Loom Co. Limited for the loan of the block for Fig. 10.

The Paper was written at the invitation of the Directors of Tootal Broadhurst Lee Co. Limited, by whose kind permission it is now published.

1956 Conference on
"PROBLEMS OF AIRCRAFT PRODUCTION"
University of Southampton, 6th - 7th January, 1956

PROGRAMME

Theme : "SPEEDING AIRCRAFT PRODUCTION"

(This section of the Journal contains a report of **Sessions III** and **IV. Sessions I** and **II** appeared in the March issue)

SESSION I

Chairman : Sir Walter Puckey, M.I.Prod.E., F.I.I.A.

The Lord Sempill Paper

"BRITAIN'S AIRCRAFT NEEDS" by Sir Roy Fedden, M.B.E., D.Sc., Hon. F.R.Ae.S., M.I.Mech.E., F.R.S.A., Hon.F.I.A.S., Hon.F.S.A.W.E.

SESSION II

Chairman : E. F. Gilberthorpe, A.M.I.Mech.E., M.I.Prod.E., A.M.I.I.A.

"TIME CAN BE SAVED — IN THE AIRCRAFT INDUSTRY" by H. G. Gregory, M.I.Prod.E. and A. Vines, A.F.R.Ae.S., A.M.I.Prod.E.

SESSION III

Chairman : H. W. Denny, M.I.Prod.E.

"CONTROL OF PRODUCTION PROCESSES" by I. R. Smith.

SESSION IV

Chairman : S. P. Woodley, M.B.E.

"MACHINING RESEARCH AND ITS IMPACT ON SPEEDING PRODUCTION" by D. A. Oliver, C.B.E., M.Sc.(Eng.), F.I.M. ; T. S. Lister, B.Sc., A.I.M. ; D. Fitzgeorge, Ph.D., A.M.I.Mech.E. ; and M. D. Kinman. *(This Paper was sponsored by the Machine Tool Trades Association.)*

SUMMING UP

by the Right Hon. Lord Sempill, A.F.C., Hon.M.I.Prod.E.

SESSION III

CONTROL OF PRODUCTION PROCESSES

by I. R. SMITH

Mr. Smith

Mr. Smith was educated at King Alfred's Grammar School, Wantage, Berks, and served an aircraft engineering apprenticeship in the R.A.F. Workshops at Milton, Berks. He joined the A.I.D. in 1935, resigning in 1948 to join the Airspeed Company, Ltd., Portsmouth, as Deputy Chief Inspector.

In 1950, Mr. Smith was appointed Chief Inspector of Chrysler (Australia) Ltd., Aircraft Division, on Canberra production in Australia. He returned to the United Kingdom in 1954 and took up his present post as Chief Inspector of the Aircraft Division of the Bristol Aeroplane Company, Ltd.

THE object of this Paper is to attempt to convey the control techniques and attendant problems associated with production processes. It will be appreciated that it is beyond the scope of the Paper to attempt to cover all the processes used in the production of the modern aeroplane. I propose therefore, to review the general principles applied in the approach to this problem, including current developments and outline my views on the shape of future control techniques. To this end, I have broken my subject into four main group headings as follows :-

1. Control of Material.
2. Control of Manufacture.
3. Control of Special Processes.
4. Current developments and the shape of Future Control Techniques.

Control of Material

If one considers this subject it becomes apparent that whatever production processes are in use, they must necessarily have stemmed initially from design. The designer, in creating his aeroplane, selects his materials and processes to provide him with an estimated result ; it would therefore appear logical to commence by examining the subject right from the design stage, and, having recognised the need, follow through with the method of control.

Creating the Requirements

The designer, having carefully studied the customer's specification, proceeds to examine the list of available materials and selects those which, in his opinion, will meet or approximate to the envisaged stress and strain factors in his initial calculations.

The material is then procured from an approved manufacturer, i.e. a firm who have satisfied one or both of the approved authorities, viz. A.I.D. and A.R.B., that the manufacture of their product has been controlled and inspected at each stage thus ensuring their product is manufactured to the requirements of the appropriate specification. This is achieved by chemical analysis and physical test procedure by an approved laboratory and ultimately certified on release. On receipt of materials it is necessary in certain instances to carry out check tests to verify the manufacturer's control.

Design Standards

The Engineering Development Section then proceed on a course of experimentation and put the materials through tests as near as possible to the known environmental conditions to ensure that it will be suitable in all respects. The data thus obtained is tabulated and forms the basis of the guiding document circulated to all production departments in the form of technical notes or process instruction, giving details of special techniques to be applied, tolerances to be adhered to, heat treatment figures and tests to be applied, etc.

This document embraces the requirements of AP.970 Design Requirements for Aeroplanes ; British Civil Airworthiness Requirements ; AP.4089, Inspection Instruction Leaflets ; and is generally issued by the Engineering Development of Process Laboratories.

Having concluded his months of calculation, testing, and experimentation, the designer has produced and circulated his instructions on the standards to which he requires the various component parts produced, and thus the process of control commences.

Control Technique

On receipt of material, a test piece is submitted for chemical analysis and physical test as described above. The identity of the material as received is maintained by the batch control system. By this method, the manufacturer allocates a number to a complete batch of material produced. This number is used to correlate all subsequent relative tests, etc., and is maintained in the case of Class 1 parts for the purpose of tracing the life history of material when an investigation has been found necessary due to failure. This is done by marking the material, in some instances, and by inspection records in others.

When testing has been satisfactorily concluded, the material is colour coded according to specification and finally passed into Stores. During storage, care in handling, storage, cutting and issuing of material is supervised by Stores Inspection.

Production having completed their planning procedure, etc. and having obtained the necessary drawings, withdraw the material from Stores in readiness for manufacture, which brings me to the second main group heading.

Control of Manufacture

Inevitably, the first stage of the process of manufacture where manipulation is necessary, is heat treatment. The term "heat treatment" is of course a very broad one when one thinks of aircraft production, since such a variety of material is used and so many varying treatments become necessary. However, two major principles of control must apply :-

1. It is imperative that close control of the pyrometry, used on the furnaces or bath, is maintained.
2. Adequate information on temperatures must be available, either from the manufacturers of the material or from specification.

Many specifications require that the materials which they cover shall be subjected to heat treatment in order to develop the properties required. Some materials require treatment between very close limits, especially if treatment exceeding the specified maximum is liable to leave the material in an unsafe condition which cannot be readily detected by visual inspection or routine testing.

It is therefore necessary when applying control to the process to verify that :-

1. The material is heated to specified temperature or within the limits called up.
2. The instruments used for measuring the temperature are accurate.
3. The instruments are so installed and maintained that they correctly measure the temperature of the material being tested.

Control of Equipment

On initial installation of a furnace or bath with its measuring equipment, checks must be carried out and certification provided of the temperature measuring equipment accuracy which must be to within $\pm$ 1% of the true temperature.

It is necessary to take checks for uniformity of temperatures throughout the heating medium to ensure that no hot or cold spots are present, and an adequate number of thermometers or pyrometers are installed to record the uniformity. The installation must be such that the temperature of the material under treatment is accurately measured.

It is necessary to correlate heat treatment of batches with the temperatures used ; this can be done by the use of recorders, the batch numbers being logged on the charts at the time of treatment. It is also necessary to maintain a heat treatment log of all material passing through.

Checks must be made once a week on an installation and may be carried out with a master couple and a master potentiometer. This checking instrument is usually certified by the National Physical Laboratory or the makers of the equipment—it is required to be to an accuracy of ± 2°C. of the true temperature for instruments up to 600°C., and to within ± 5°C. for instruments reading between 600°C. and 1200°C. The certificate states in degrees the actual errors at the temperature of calibration.

The maintenance of accurate pyrometric installations is of primary importance, since failure to exercise proper control at this stage may be a delaying factor in production due to the necessity of closing down the equipment to carry out repairs.

Control of Material Being Treated

Whenever it is necessary to heat-treat material, it is important that an indication of the final condition of the material is obtained. This can only be done by physically testing the material and noting its mechanical properties.

Since it is not possible to obtain this information from the part itself, the system of test piece control is accepted practice.

The method of applying this control is to ensure that a piece of the same batch of material to be treated is routed with the parts or material to the heat treatment section and is subjected to exactly the same treatment. A test piece is then cut from this control piece and passed to the Mechanical Laboratory for the required tests to be carried out. It is essential that correlation is maintained with the parts or material treated so that in the event of the tests being unsatisfactory, action can be taken to quarantine and investigate the reasons for failure. Wherever possible, in addition to the control of the process by test piece, hardness tests are carried out on each part to ensure that uniformity of treatment has taken place.

In the case of light alloy sheet where treatment is necessary for ease of manipulation during manufacture, it has been accepted that control of the salt bath can be adequately maintained by bath control : that is, in place of a test piece for each batch of

material being treated a test piece is used to indicate correctness of control of the process itself. It will be seen therefore that control is exercised by two methods :-

1. the furnace or bath ;
2. the material and the furnace or bath.

Parts used in secondary structures or where treatment is for forming purposes only may be controlled by method one, but it is imperative that where parts of importance are treated individual batch control is maintained.

Welding

Another major process used in aircraft production which we may well examine is welding. This is a process which requires very close control by virtue of the fact that true indication of the result can only strictly be obtained by destroying the part. This is obviously impracticable. It follows, therefore, that the emphasis of control must be directed to the operators, the materials, the equipment and techniques, supplemented by non-destructive testing.

Approval of Operator

Insofar as fusion welding is concerned, no operator may be employed on welding aircraft parts other than unstressed items until he or she has passed a test for competency. This control is necessary, since the process is dependent upon the individual welder's skill. Evidence of competency is obtained by test welds on standard test specimens which have been prepared by each welder for the group of materials on which they are to be employed. The test welds are then sent to the laboratory where mechanical and micro tests are carried out. Each welder is given a code identification against which are recorded the tests undergone on each type of material or process, check tests on proficiency being carried out periodically, usually every six weeks.

Approval of Materials and Techniques

The inspector has to verify that only approved materials are being used, i.e. that the material being welded has been certified as suitable for welding, that the proper welding rod and flux obtained from an approved source are being used, and that visually the final weld is satisfactory in that there are no signs of burning or porosity, incipient cracks, proper penetration has been achieved, the weld is of a regular and suitable size, and no reduction in thickness has resulted. In the case of light alloys it is important that all traces of flux have been removed.

Equipment

Equipment is usually maintained in accordance with the manufacturer's instructions. However, the following checks must be carried out :-

1. Nozzle size and gas pressure for correctness.
2. Flame adjusted to near neutral.
3. Gases checked for impurities.
4. Electrode size and current rating for correctness.

Resistance Welding

Electric spot welding is used today on both stressed components and secondary structures — it is therefore essential that control of the process is exercised.

Spot welding machines are entirely automatic and once set are capable of operating and producing satisfactory welds if certain conditions are met. These conditions are as follows :-

(a) Pressure, period of pressure and heating current values, etc. are in accordance with experiments having been carried out with the particular type of weld and machine used.
(b) The surfaces of the material are clean. This can be done by chemical or mechanical means.
(c) All the drawing requirements are being complied with.
(d) Electrodes are maintained in a clean condition and are of correct form as laid down by the makers of the machines.
(e) The surface of the material does not show signs of over-heating.
(f) The welds and the metal in the vicinity show no sign of cracking.
(g) The indentations of the electrodes should not be greater than 10% of the thickness of the sheet.

It is practice to carry out a series of tests on a machine, comprising all the various gauges of materials requiring to be welded. These tests are then tested in the mechanical laboratory and when satisfactory to the minimum strength requirements laid down by the designer on size and strength of spot, a schedule of setting is compiled and displayed near the machine for the operator to work to.

Before commencing a production run it is necessary to carry out a test on samples simulating the production parts in respect of gauge, class of material and pitch of weld spot : it is also necessary to repeat the test at the end of the day's run or whenever new settings are made. Tests are also required after replacement of electrodes.

It is also usual to carry out checks on production parts in order to be satisfied with the efficacy of the process.

A similar control is applied when stitch or seam welding is to be used.

It will be appreciated that I have only touched on two of the major processes involved in manufacture, but I feel that some indication has been given of how and why it is necessary to exercise control and I would like to stress the importance of maintaining this control efficiently in order to allow production to flow smoothly.

Control of Special Processes

Today we are faced with processes which are the outcome of development of new material. These processes require close control to ensure a satisfactory end product, two examples of the type I have in mind being :-

1. metal to metal adhesive ;
2. plastics.

In order to indicate the control which is necessary, I would like to review these two subjects.

Metal to Metal Adhesives

There has been an increasing trend by designers to use metal to metal adhesives in order to save weight. The development of these adhesives has been such that they are playing a more and more important part in aircraft production.

Without wishing to specify any particular product, an indication can be given of the control exercised and the reason for that control.

The initial requirement of a good bond is the fit of the parts to be bonded. It is essential that mating parts fit together to keep the glue line to a minimum thickness in order to keep within manufacturing tolerances and give maximum strength of joint. The next important requirement is cleanliness of parts before applying the gluing medium. This cleanliness is usually obtained chemically and close control of the cleaning process is essential.

With these two requirements satisfied the dominant factors are : time, temperature and pressure.

The time of cure must be that specified by the manufacturers and is taken from the time that the glue line has reached curing temperature.

The temperature must be maintained at that specified by the makers and the provisions of control of pyrometry must apply as rigidly as that applied in heat treatment installations.

It is important that, where autoclaves are used for curing the adhesive, care is taken when loading the autoclave to ensure that jigs and assemblies of a similar shape and density are loaded at the same time, in order to try and maintain uniformity of heating throughout.

The pressure required is stated in general by the manufacturers of the adhesive. It will, however, be found that assemblies of unusual shape and varying gauges require some development in order to establish a satisfactory pressure.

The method of control used in this process is again that of control test pieces. The test piece size is quoted in the D.T.D. specification and consists of a 1″ wide strip of D.T.D. 546 with a ½″ overlap joint. This is, of course, a shear test specimen. I consider that the test specimen should be cured with the parts, since it is intended to be representative of the assembly being glued together and therefore should be in a condition as close as possible to the assembly.

The peel test has been used as control of this process—this consists of two strips of D.T.D.610, 20 SWG 1″ wide, one strip being 12″ long the other 8″ long, the two of them precleaned and bonded over a length of 7″. The bonded test piece is then wrapped around a drum, 6″ diameter, which is placed in a hand loaded machine and the load applied at a rate sufficient to cause upward movement of 2″ per minute.

For control purposes, the component is pressed simultaneously with a panel from which six test specimens are cut and the results are acceptable if not more than 15% of the collective lengths as recorded on the graph at time of test, falls below 21 lb., and provided that not less than 60% of the collective lengths fall above 30 lb.

We, at Bristol, have found such a wide scatter in peel strength as to cause us to discontinue its use as a control and to rely entirely on shear strength specimens.

With this process strict control is necessary throughout from pre-cleaning to completion of cure, with accurate recording of times, temperature, pressure and finally test results obtained.

Cleanliness is vital and disregard of this requirement can only lead to high scrap rate and consequently hold ups in production.

Plastics

This material has been rapidly developed in the past ten years or so and is now being effectively used in the manufacture of a wide variety of parts and components embracing small electrical insulators and major structural components.

At Bristol, our range of materials can be conveniently split into two main groups :-

1. Thermoplastics ;
2. Thermosettings.

Thermoplastics

This includes Perspex, Darvic, Polythene, Cobex, P.V.C. and Durestas. Of these, perhaps Perspex is the most common and so, if I may, I will use this material for the purpose of demonstrating the control technique.

During manufacture, the material is controlled by specification. However, to ensure that each day's manufacture is proved " by the laws of probability ", two specimens selected from different sheets are tested daily for tensile strength; three specimens are tested for impact value and one sheet in every fifty is selected for testing under moulding temperatures. A full specification check is carried out at three monthly intervals or at each change of manufacturing technique. Provided satisfactory results are obtained, this will be the measure of control ; failures will naturally result in an increase in the number and periodicity of checks. Satisfactory panels are stamped and released according to grade.

On receipt of Perspex, it is physically checked and passed into Stores. To ensure that its properties and qualities are maintained, it is essential to ensure that it is properly stored, with adequate protection from surface defects, sunlight, dust, paint, oils and solvents, etc. This is achieved by resident inspectors who maintain a constant vigil on their appropriate section of the stores to ensure that such materials are not adversely affected due to unsatisfactory storage. Quality control inspectors supplement this by doing a monthly check and their findings are reported to the Chief Inspector.

The Perspex is issued for shaping and thus manufacturing technical notes come into the picture. In this, the designer again specifies the temperature, time, and gives tolerances where permissible. The control, therefore, is to ensure accuracy in measuring these factors and also have a reliable recording system.

In some instances, this is done automatically by such as Kent Recorders and in other cases by the direct reading from gauges. The time "in" is recorded in a record book, together with the time "due out" and "actual time out". This is physically checked by a patrolling inspector. Perspex would be heated to a temperature in the order of 135—155°C. for a time calculated according to gauge, using the formula $T=10+80x$ where x is the gauge of material. The tools which are used for shaping are controlled by the usual tool control methods, including first off inspection and are usually made from wood or plaster. When the shaping and forming is complete, the Perspex must then be checked for signs of strain by means of a Strain Viewer and of course, checked for transparency and signs of distortion or surface defects. Burrs and sharp edges, etc. have to be removed following drilling and cutting operations, as they are potential fractures.

During assembly, there remains to ensure that no strain has been built into a panel and also to preserve it during the completion of manufacture of the aircraft, avoiding contamination of paints, dopes, thinners, solvents, etc.

Thermosettings

In this group, we have such materials as moulding powders, Durestos, asbestos felts and flock.

Manufacture of components from these materials, although varying slightly in technique, e.g. pressure applied at a given temperature for a given time, heat introduced through the tool, etc. does not alter the principle of control which is virtually the same as for sheet material.

Araldite is one of the materials which are sample checked by the Works Laboratory on receipt of each batch and the mixing is an added control check. In some instances, this is achieved by utilising a similar system to that for rivet control, where a colour scheme is applied so that one can readily see that the 'mix' is being used within its keeping time.

It will be readily seen that the principle of control is virtually a constant. It varies only in method of application and insofar as plastics are concerned, the only time-saving possibilities lie in the production of completely automatic mixing, moulding, temperature and time cycle control.

I would add that I am not pessimistic about the possibility of such an automatic form of control and it is the obvious trend for the future.

Current Developments and the Shape of Future Control

With development of aircraft design towards higher speeds and greater all-up weight, it is inevitable that more and more must be known about the materials we use and the processes involved in their manipulation. One cardinal point stands out—it is imperative that we be assured that the material we use is as near perfect as it is possible to be. The current developments are the use of dye penetrants for the detection of surface defects ; ultrasonics for the detection of sub-surface defects ; and X-ray for the examination of structures.

Ultrasonics

A recent visit to America revealed that ultrasonics are playing an increasingly important part in the quality control of raw materials and finished machined parts.

It was apparent that whilst the Douglas Aircraft Corporation had advanced to a marked degree in the application and development of ultrasonic inspection, the aircraft industry as a whole in North America was fully aware of the position and in all cases were taking steps to benefit from the progress already made by Douglas and the equipment manufacturers.

The general impression to be gained was that the manufacturing industry felt that the main responsibility must lie with the raw material suppliers. In the case of light alloy this point of view is rapidly being accepted, so much so that in certain instances manufacturers are now not only inspecting the billet, but have been forced to a closer control of the actual casting process.

Notwithstanding the acceptance of this principle by the manufacturers of raw material, it is still considered necessary to operate a pilot plant as a means of quality control of suppliers.

It was very evident that the advance in the design of the electronic equipment in North America was much greater than that in this country. This opinion is based on the fact that prior to our departure an investigation was made of all available equipment in this country. A further advance has been the development of the lithium sulphate crystal, which has proved to be far superior to either quartz or barium titanate, having a greater damping effect and giving a much better resolution of signal ; whilst they are considerably more expensive, the results obtained justify the additional expense. The technique of immersion scanning, which is the basis of all ultrasonic flaw detection in North America, is one which they have proved without any doubt to be the most effective. Prior to our departure, this technique was still in the laboratory stages in this country and some confliction existed of its efficiency. It is felt that this difference of opinion was based largely on the fact that the loss of power was excessive. It must be pointed out, however, that the sets in use in America have a much higher output than those at present available in this country ; the main advantage being obtained from immersion scanning is the fact that it is possible to orientate the crystal in relation to the defect and obtain maximum echo response from the flaw. A further advantage is that since the crystal is not in direct contact with the material no wear takes place.

In all instances ultrasonic inspection is applied on a comparison basis, test blocks having known flaws in the various types of materials being used as standard of operation and comparing signals obtained on the test blocks against signals received on possible flaws in the material. Evidence was presented on the considerable saving in labour costs by rejection of faulty material.

In the case of the Douglas plant, it was stated that a 90% accuracy had been obtained in the detection of flaws in large plate and forgings ; numerous samples were shown to substantiate this statement.

In all cases rejection of the material has been accepted by the suppliers. Due to the fact that ultrasonic inspection reveals the smallest of flaws, it has been found necessary to compile a standard acceptance specification of material condition.

The control of operation of this process is one which requires an individual with the knowledge of electronics together with a programme of development using the knowledge we have gained from our visits. It should then be possible for us to ensure that labour is not wasted on sub-standard material and that the quality of our final product is beyond any shadow of doubt the finest that can be obtained.

Penetrants

The fluorescent penetrant process for surface flaw detection in non-ferrous metals is considered to be the most efficient method available and has become standard practice in all aircraft factories visited. It is considered to be superior to anodising as a flaw detection process and is generally more convenient in production.

The process consists of a penetrant tank, wash tank, drying tank and developer tank, the parts being finally inspected under an ultra-violet lamp in a curtained booth. A further development has been the introduction of what is known as " Post Emulsifier ", a material which has a far higher degree of penetrating power and the capability of overcoming all other foreign matter, which may be present in the surface cracks.

Magnetic Crack Detection

With reference to magnetic crack detection, the only advance on the accepted practice in use in this country was the use of " Magneglo " crack detection ink which combines magnetic crack detection with fluorescent crack detection, parts being inspected by ultra-violet ray lamp.

X-rays

The application of industrial X-ray was found to be on a similar scale to that employed in this country, though the Douglas Aircraft Corporation has successfully applied X-ray technique to inspection of complete aircraft structures where known defects had arisen. Again, this process can only be applied on a comparator basis, comparing results shown on the radiograph with defects that had previously been inspected on other aircraft, visually.

It is intended to keep a complete chart of all defects reported by operators and where possible to correlate these with Service Bulletins giving full information on the X-ray technique to be used, such as location of set, angle of shot and length of exposure. Whilst this process is in a very early stage of development, it is thought that it shows considerable promise, since the saving in manhours can be appreciable where stripping of furnishings for the necessary visual inspection would be necessary.

Enquiries into the use of fluorescent screen X-ray showed that only one set was in use and that was at the Douglas Aircraft Corporation in the Goods Received area.

A demonstration of this equipment on Class 3 castings and sealed electrical units showed surprisingly good definition, and it was stated that the equipment had proved of great value in checking quantities of sealed items where one had failed and the cause of failure was visually apparent.

It had also been possible to rapidly inspect some plastic aerial masts with metal inserts where the location of the inserts had proved critical.

I have endeavoured to show how the control of Production Processes operate and to indicate that efficient control prevents waste and loss of time. Today the highest cost is labour; it therefore follows that judicious and efficient control will prevent labour wastage. The next highest factor is delivery time on material or parts and here again efficient control can ensure smooth production. If parts are made correctly from sound material, much can be done to speed aircraft production for a job done more than once is wasteful and delaying. Controls to the Production Manager may often seem irksome, but if he will stop and think he will realise that he stands to gain most from them. You must also, gentlemen, begin to realise that as the present trend continues more and more controls will become necessary, since reliability must become the keynote of all our supplies and processes, reliability in the final result.

REPORT AND DISCUSSION

Mr. I. R. Smith, in presenting the Paper, (which appears on pages 242-247), said that among so many production managers he felt rather like Daniel in the lions' den. He had heard it said that inspectors were inverted Micawbers, waiting for something to turn down. That was an entirely erroneous idea; the function of the inspector was simply to confirm that the part had been made correctly.

When dealing with control technique, he emphasised the necessity for industrial discipline in the handling of materials, and especially what might be called the tricky materials such as 683 and magnesium. Sufficient was known about the problem to realise that virtually nothing was known about these materials; all sorts of odd things were happening and efforts were still being made to find out why they happened. He

had seen instances where the handling of these materials left a good deal to be desired, and much could be done to educate everyone to realise that untold damage could occur through bad handling.

Another point which caused great embarrassment to chief inspectors today was damage occurring to sheet metal, especially where skins for pressurised fuselages were concerned. That became a real problem when the fuselage had been built and there were scratches everywhere and they did not know what to do about it. A stage was being reached where new materials, and particularly stainless steel, must have a high degree of accuracy in manufacture, and particularly flatness. This in itself could introduce problems of storage and handling.

Dealing with metal-to-metal adhesives, he said that investigation was being carried out to attempt to discover some simple means of positive indication of bond strength. In America a Committee at the Stanford Laboratory was investigating the Stub meter which had been developed, but the reports to date were not enthusiastic.

Under the heading of " Ultrasonics," and referring to the responsibility of the suppliers of raw materials, Mr. Smith said it would be realised that the light alloy industry had an enormous market in the aircraft field, but that was not so with the steel supplier. The quantities of steel used by the aircraft industry were small compared with the demands of the other engineering industries. That applied also, of course, to America. In the light alloy field the Americans had reached a very good standard of quality for all material, but they were having a good deal of trouble with steel, and he had found that they were getting up to 65 - 70% rejections when checking large bars of steel.

While it was stated in the Paper that the advance in the design of the electronic equipment in North America was much greater than that in Britain, that must be qualified by saying that it referred to equipment in general used in production and not just in the laboratory stage.

On the subject of magnetic crack detection, the claim was made that the use of Magneglo lessened operator fatigue and therefore gave a higher rate of parts going through.

Under the heading " X-rays," and dealing with the use of the fluorescent screen X-ray, Mr. Smith said that he had found that these screen sets were used a good deal in this country in the food trade, for chocolates and so on. He felt that the method would be useful in the aircraft industry for the rapid checking of sealed units where defects arose and it was necessary to go back and check stock holdings, for instance. A problem arose owing to the degree of intensification obtained not being very high, but developments were being carried out in this country and there had been demonstrations of image amplification which might solve the problem.

The Chairman said that Mr. Smith had given his audience a number of subjects to think about. Those who were in the aircraft industry would, as he had said earlier, be familiar with a number of them, but no doubt some members would like an amplification of some of the processes mentioned in the Paper. One which interested the Chairman was that which permitted the X-ray examination of structures. It would be interesting to have a fuller description of this process, which the aircraft frame makers might find very useful.

Mr. Smith replied that, as he mentioned in the Paper, the development was a very new one, and arose out of an inquiry by an operator in America directed to the Douglas Aircraft Corporation, after finding cracks on inspection on a DC.3. Douglas felt that they had to do something about it. They dismantled the wings to inspect them and, having seen what the defect looked like, they thought that they would try X-rays and see whether they could find it on the radiograph. They found surprisingly good definition, and promptly X-rayed the remainder of the fleet. They were able to establish where the defect was present and which aircraft were clear and could proceed.

Developing that theme, they were now working on a scheme whereby operators reported to the manufacturing company any defects found during the check inspection periods, and, where these defects were found and fatigue cracks occurred, they logged them on the G.A. of the aircraft. They also marked all other areas where cracks had been known to occur, and thus they built up a case history of the particular type of aircraft, the defects which developed in service and the times when they had been found.

They then worked out a technique of X-raying the structure in that area by locating the set inside the fuselage or in the best place to secure a similar result to that seen visually. That had to be done on a comparative basis, because when X-raying structures — he was not an X-ray specialist — it would be appreciated that the varying densities of materials and the number of things in the way made the interpretation of the radiograph far from easy, and it was therefore much better to know what one was trying to find.

Having done that, the Douglas Corporation were compiling a bulletin which they sent to operators giving them full information of the area to be radiographed, the angle of the shot, the degree of exposure and what to look for when the film was developed.

They told him that in the case of the small fighters, they X-rayed them completely from wing-tip to wing-tip and tip to tail, mainly with the idea of seeing whether the layout of the electric cables and the " plumbing " was good, because a great deal was packed into a confined space and the X-ray showed up things which had been left in the aircraft. They found all sorts of things, apart from tools, and these showed up very readily, of course, on a radiograph. He thought that there was a great deal to be said for using this method.

Mr. E. D. Keen (*Chief Designer, Sir W. G. Armstrong Whitworth Aircraft Ltd.*) suggested that it must be very difficult to get X-ray photographs in the vital spots with the normal type of apparatus, and

asked whether Mr. Smith knew of any work which was going on in the obvious use of radio-isotopes in this field. The time of exposure, he said, might have to be very long in some cases, but it seemed an obvious application, and he believed that this country in the general field was far ahead of the rest of the world in the use of radio-isotopes. Was anything of that kind being used so far as aircraft were concerned?

Mr. Smith replied that isotopes were being used for places where it was not possible to employ an X-ray set. In the current issue of the Journal of the Society of Licensed Aircraft Engineers, there was a Paper by Grant Murray, the Chief Inspector of the B.E.A., describing how they used isotopes for this purpose. In the main, however, Mr. Smith felt that, due to the half-life of the isotopes and the length of exposure required, operators would prefer to use a portable X-ray set.

Mr. Oliver (*Director of Research, B.S.A. Group of Companies*) expressed interest in Mr. Smith's remarks on ultrasonics, and particularly his welcome to the U.S. immersion method, and asked first of all what size of parts were actually tested in that way. He had heard of gas turbine blades being effectively examined by immersion methods, but they were comparatively small parts. Perhaps Mr. Smith could amplify his remarks on the subject by saying how large were the billets or parts which were now being examined by the immersion method.

It was perhaps not realised how much ultrasonic inspection was now carried out on high quality aircraft steels. William Jessop & Sons Ltd., Sheffield had done 100% inspection of gas turbine discs by ultrasonic methods for the last ten years or more. A recent development had been the examination of blooms prior to forging into billet or final components as an intermediate stage inspection between the bloom and the final forging. The procedure was to forge an ingot to a bloom of a certain diameter; to machine flats the whole length of the bloom and then do a transmission ultrasonic test to examine the density of the actual structure; and then, in the case of a gas turbine rotor (or a steam turbine rotor or whatever it might be) to throw the forging along the length of the complete bloom so as to put the vital parts in the soundest area. For instance, if there was a portion which was not intrinsically unsound but just a little "loose," as the saying went, that could be thrown into the shaft ends, where it would be of adequate quality; but where there was to be a violent change of section one would make sure that that region was thoroughly sound.

He could assure Mr. Smith that some research was going on in this country to follow up the original Russian claims of having a kind of ultrasonic microscope. They reckoned to get a complete picture, just like an X-ray radiograph, but the whole thing was ultrasonic. It employed the universal scanning method. He thought that the immersion method referred to in the Paper had limitations, because reference was made to having to revolve the specimen to check up on the defects. In the system to which Mr. Oliver referred it was not necessary to revolve anything; the specimen was subjected to ultrasonic waves at all angles, and the picture on the screen was like a television picture and showed the variation of density throughout the body of the component.

Mr. Smith, referring to the size of the equipment which he had seen in America, said that the largest tank was 50 ft. long by 25 ft. wide, the scanning being at the rate of 18 in./sec. Alongside the crystal probe was a grease pencil which left a mark in the particular spot where a defect was suspected, and on the completion of scanning a complete trace was obtained and the operator would go back over it. This was being made for the Kayser Aluminium Company of America, and it indicated the length to which the material manufacturers were now going to ensure that their product was sound.

With regard to the inspection of steel, his opinion was that America was not as fortunate as this country in that respect, because most of the American steels were made to general engineering specifications. In this country there was a much closer control of the material and the aircraft industry was supplied with material in accordance with its specification requirements. That was of interest from the point of view of quality control. He found that in America the quality control organisations were extremely large, and he thought that that was necessary, due to the fact that they had not the A.I.D. approved system of firms, where the approval was vested in the individual. The approval of the manufacturer was based merely on the facilities of the plant. Where ultrasonic inspection was laid down a note had to be furnished to say that it had been done, but there was no general provision, and therefore every manufacturer had to ensure that whatever he was supplied with was entirely satisfactory. Enormous control organisations were therefore necessary. Their rejection rate for steel was probably due to the fact that control of the manufacture of the steel was not as rigid as in this country.

Although the use of ultrasonics had been known for a long time, their application to the aircraft industry was comparatively new, and it was a specialised field about which he knew very little. He felt that tremendous strides could be made in the development of the application of this science to engineering and that it should be of great benefit to the aircraft industry, but it was difficult to keep up with all the developments.

Mr. A. E. Woodward-Nutt (*Principal Director of Aircraft Research and Development, Ministry of Supply*) said he fully agreed with all that Mr. Smith had said about the importance of control and care in handling materials. He felt that if everyone could always exercise the degree of control described, there would not be half the trouble that occurred nowadays. In particular he was thinking of that hardy annual, the high strength light alloy such as DTD.683.

Recently in the Ministry of Supply a further examination had been made of the troubles which had occurred during the last few years with materials

of this kind, and once again the conclusion had been reached that so long as the material was properly manufactured, properly controlled during manufacture, properly stored and handled and properly controlled during fabrication, it should be satisfactory in service. He would add the obvious point that the parts to be made of it had to be designed accordingly.

That raised the question whether the control required was more than could normally be expected to be achieved. Mr. Smith had referred to the material as "tricky". That might be so, but the country might need it to win the trick and the rubber. It would be quite easy for the Ministry of Supply to say "This material is tricky and difficult ; we get an unreasonable proportion of troubles with it, and the precision of control required is too much to expect aircraft and component manufacturers to exercise.". But was it ? That was the question which he wanted to ask. His own view was that if all aircraft manufacturers could be relied on, as he thought that most of them could be, to exercise the degree of control which Mr. Smith described as essential the position would be satisfactory. Was that in fact too much to expect ?

He had one further question, about the X-ray examination of aircraft, and in particular the tip-to-tip examination of fighters. Had Mr. Smith any information on the cost of that ?

Mr. Smith replied that when he had referred to certain materials as "tricky", he meant that they involved dealing with a certain number of unknowns. He thought that everyone tried to apply the maximum control to ensure that the finished product would be satisfactory, but in his experience there was always something for which it had not been possible to cater which suddenly appeared. He had been confronted with complete undercarriage forgings which on final inspection after machining had shown minute cracks, or perhaps only one. Metallurgists told him that they could give him no complete assurance of what lay underneath the crack ; the only thing to do was to keep on removing material until there was no further sign of it. In referring to "tricky" materials, he did so in that sense. When so much was unknown, care in handling was a factor which should help to rule out the possibility of damage occurring at that stage. He had seen spar booms picked up by a centre sling, and in lowering them one end had touched the ground first and then the whole bundle dropped. Damage which was thus caused might not show itself until later, when the parts were being machined or manipulated.

He was sorry he could not give the cost of X-ray inspection. He imagined that it was fairly costly initially. He was quite open-minded on the value of it. He felt that there was a field for the application of X-raying of complete structures with guided missiles ; these weapons were so packed with cables and pipelines that complete X-raying should be useful, particularly in the prototype stage.

Mr. S. G. E. Nash (*Deputy Chief Development Engineer, Bristol Aircraft Ltd.*) said that Mr. Smith had given a very comprehensive view of the material means by which control was exercised, and he would probably agree that most of the "rubs" between production and inspection occurred in what might be called the area of the philosophy of inspection or, in other words, in the human relations field. Mr. Smith had laid the onus for formulating requirements very heavily on the design offices. Perhaps he became as irritated as anybody else with the inspector whose view-point was the somewhat narrow one of the traditional defence that "It's not on the drawing".

It would be interesting to know how far Mr. Smith considered it the duty of the inspection branch itself to evolve requirements and methods of inspection. There would always be some intangible requirements which could not very well be stated on the drawing, but which were most important integral parts of the assessment of the job as a whole.

A second question was that of responsibility for the ultimate rightness of the part. In that connection Mr. Smith had mentioned industrial discipline. The rigours of industrial discipline seemed to be far more frequently applied to the inspector than to the man engaged on production.

From time to time assessments were given of what was a reasonable proportion of inspection staff in a factory. In the average British factory it was probably of the order of 15 per cent., but very much lower figures had sometimes been quoted for the American scene, and he gathered that it was common in America for the first line of inspection to be provided by the production supervisors. He would like to know what Mr. Smith's recent experience had been in that respect, and whether he thought that it was possible to give junior production supervisors some inspection training so that they could carry out that function.

Mr. Smith, dealing with methods of inspection, said he felt that the designer could only specify on the drawings the minimum requirements of dimensions, tolerances, heat treatment and so on. Methods of inspection must necessarily, he thought, be a matter of experience. Most inspection documents were compiled by people with a wide experience of the requirements of the parts and processes, but where special processes were evolved by a development department or laboratory they were the only people who could lay down the type of control which was required, and they must indicate where the control was necessary.

With regard to industrial discipline, it might be that that was not a good term for what he was trying to convey. It was a question of education, of educating the personnel to handle the materials properly.

He had naturally been very interested in the inspection coverage in America and had made a point of trying to get an assessment from the various plants which he visited. It was very difficult, inasmuch as their form of organisation differed from that in Britain, but in the main he would say that the

proportion of inspectors to people engaged in production in America was very similar to that in this country, being between 12 and 15 per cent.

Capt. Q. P. Whitford (*Senior Development Engineer, British Oxygen Engineering Co. Ltd.*) said that his firm were comparative newcomers to this field, and he had been most interested in the degree of meticulous inspection which was required, which was even higher than for medical equipment. He wished to ask Mr. Smith whether the inspection he had seen in the United States was better and more meticulous than that in this country or not.

Secondly, his Company were very interested in welding, and were anxious to learn as well as to make available the information at their disposal. Their Sales Technical Service Department at Cricklewood were extremely interested in new developments in the welding of the tricky materials which had been mentioned and would be glad to give any help in their power. In some cases the subject was still in an embryo stage.

Mr. Smith confessed that he found it very difficult to answer the question of how inspection in America compared with inspection in Britain. His visit to America, he said, had not been for the purpose of investigating methods of inspection ; he had had specific terms of reference and had discussed inspection questions only after carrying out those terms of reference. He had been interested to find that there was a great similarity in the industry universally ; the problems were the same, the approach to solving them was identical and the answer was usually the same, which he found very gratifying, since so many of the solutions were in accord with his own views.

Mr. Nash had referred to production supervisors assuming responsibility for inspection. Mr. Smith had found that that applied in a number of plants, mainly because by the American principle of efficiency in housekeeping it must essentially be a production responsibility ; and within the efficiency target which was set, and which was highly competitive between various sections of the plant, the production supervisers had to ensure that the parts which they made and put up for inspection were satisfactory for inspection, thus enabling the scrap rate to be cut down.

Mr. A. Vines (*Production Manager, The Fairey Aviation Co. Ltd.*) asked Mr. Smith how he organised his detail inspection. In the Fairey Aviation Company, Mr. Vines said, they had found that inspectors with no knowledge of the job which they were inspecting, and who merely worked to drawings, were quite unable to use what was called 'discretion', and a vast number of inspectors had no discretion, not because they did not need to use it but because they had no knowledge of what they were inspecting. His Company had found that if the inspection staff were near the component which they were inspecting and got to know the assembly, and if the detail inspection staff knew the component for which they were inspecting the parts, they could use discretion and were better able to advise the press shop and machine shop inspection how much discretion they could use, because the inspector in charge of a particular component knew very well what he wanted. Did Mr. Smith adopt that principle, or had he detail inspection inspecting details only ?

Mr. Smith replied that it had long been the concept of the A.I.D. that the inspector had no discretion ; he was given a drawing and had to see that the part had been manufactured to that drawing. If a part was not correct and would not fit because it was not correct, it should be corrected or re-made. If it had been made correctly to drawing and did not fit, it should go to the drawing office for correction. It was most dangerous to give individual inspectors discretionary powers, because it could lead to great trouble. He had a staff of 500, and one could not have 500 different ideas of what should be done. He appreciated the point that in Mr. Vines's set-up, which had been described at the second session of the Conference, it was essential that everybody should work together as a team, but he did not think that, in endeavouring to do the job in the best possible way, the inspector's discretion should come into it.

Mr. W. A. Sales (*Director of Aircraft Production Development, Ministry of Supply*) said he could not help feeling that the inspectors who saw the good or the bad of production in the result ought to take a bigger part in the work further down the line. On the materials side, for example, there were various problems to be dealt with. The cast ingot had to be converted to forged properties. That was often done by the blacksmith, who was a highly skilled man, and every blacksmith seemed to have his own ideas on how to push a piece of metal about to get the required properties. Sample forgings were taken and cut up and the grain flow taken and so on, but he did not think that the inspection side spent as much time as they might in going back through that field and helping the planning people to take a hand right back on the materials side, which was really outside the aircraft industry proper.

The inspection side could do a great deal by working backwards from the knowledge which they had gained over a long period to help the planning staff to lay things out and control production methods. Such action would probably result automatically in a good job being done. One got a number of good parts and a number of bad ones, and there appeared to be a real need for finding out the reasons behind the scrap ; putting matters to rights in the production line, even back to the raw material.

Mr. G. I. A. Spittle (*Production Manager, The de Havilland Engine Co. Ltd.*) referred to the importance of avoiding double or treble inspection and of finding defects at the earliest possible stage in manufacture, and said it was hard to compare ratios of inspection in different organisations, because it depended not only on the amount and degree of inspection, but also on the efficiency of the production labour employed.

Mr. W. S. Hollis, B.Sc.(Eng.), A.F.R.Ae.S., (*Assistant Director, Aircraft Production Development Directorate, Ministry of Supply*) said that, for example, observation of the rate of strain hardening and the rate of reduction of area around the yield point, and creep were of great importance and were becoming more so. Naturally these investigations were primarily carried out by the Structures Departments, but were the firm's inspection yet repeating the tests on batches of material coming in, as an acceptance that these tests will be normal for the materials that will be used in aircraft ? Nimonic, for example, had been in common use for over ten years.

The Americans had for some time been paying attention to vacuum melting and degassing of metals for high purity. Had Mr. Smith found when in the U.S.A. whether their inspection had shown any definite improvement in quality as the result of using vacuum melted and outgassed metals ?

Mr. Smith pointed out that he was not a metallurgist but a chief inspector, and the two points which Mr. Hollis had raised were largely in the metallurgical field. His inspection department did not carry out investigations of the kind in question, or controls of that kind, which were usually done by their works laboratory or their development laboratory.

Mr. R. E. Mills (*Assistant Designer, Bristol Aircraft Ltd.*), on the question of discretion, agreed that no inspector was ever given discretion, but said that there was an inspection function which must rely somewhere in the set-up on discretion. This arose with a component which dimensionally might appear to be completely satisfactory, but in performance was not up to standard, for some reason which might not yet be known. It might be so difficult and so expensive to investigate that no attempt had been made to find out why performance was not up to standard. There might be a very complicated test procedure to prove this.

One example, out of many which could be given, was helicopter blades. The test there, after normal physical checks, was the performance of that blade. It was obviously an inspection function. He thought he was right in saying that probably the design department, or a department connected with design, had a big say in what came out there. He would like to have the views of Mr. Smith on this very important aspect of inspection, particularly in regard to prototypes, where there had been no chance of getting a backlog of history on which to base the inspection standard.

Mr. Smith was not sure that he had fully understood the question, but assumed the point was that the designer had made a bad guess. If the part was made correctly to drawing but did not give the required performance, he did not see what the inspector could do about it.

Mr. Mills remarked that the designer was always going into the unknown. He knew what he wanted, but there was a factor of ignorance involved.

Mr. Smith replied that all that inspection could ensure was that control was exercised in the manufacture of the part and that it was made in accordance with the designer's requirements. The performance on completion was something over which they had no control whatever. They could only channel back to the design department the results found and see that whatever that department required was carried out. If they did that they were providing an essential control, but the performance of the part was not a matter for them.

Mr. E. B. Loewendahl (*Assistant General Manager, Central Tool & Equipment Co. Ltd.*) said that in the Paper reference was made to the possibility of saving a good deal of time by making the process of manufacturing certain plastic materials automatic and thereby eliminating the necessity for detailed material tests. The same idea could be applied to dimensional inspection by making dimensional production automatic, as for example by using programme-controlled machines. Would they in themselves give a guarantee of correct dimensional results?

Mr. Smith thought that that was so and that there was a natural trend in that direction.

Mr. G. H. Taylor (*New Development and Process Engineer, The English Electric Co. Ltd.*) said that one subject on which Mr. Smith had not touched was surface finish, which was largely discretionary ; in very few instances was a surface finish specified. With vapour blasting, or capri honing, he was told that visible tool marks need not be removed by file and emery cloth, but vapour blasting would remove them as stress raisers. It would be interesting to have Mr. Smith's remarks on that. With the advent of vapour blasting, should they be satisfied with vapour blasting, which would not always remove visible tool marks, or would they still have to remove the tool marks, and then vapour blast ?

Mr. Smith said that in the main where surface finish was critical the designer would specify it on the drawing, and the desired result would be achieved. The general acceptance standard of the finish of the part was a matter of opinion of the individual inspector, and the new processes such as vapour blasting should go a long way to ease that problem. His own firm were not using vapour blasting at the moment, so that he had had no practical experience of it, but he was very interested in it and hoped to see it in the near future. He could not say more than that the standard of finish was a matter of personal opinion, and that, provided acute stress raisers were eliminated, unless a micro-finish was asked for they would just ask for the general standard of finish.

(*concluded on page* 273)

MACHINING RESEARCH AND ITS IMPACT ON SPEEDING PRODUCTION

by D. A. Oliver, C.B.E., M.Sc.(Eng.), F.I.M.,
T. S. Lister, B.Sc., A.I.M., M. D. Kinman and
D. Fitzgeorge, Ph.D., A.M.I.Mech.E.

1. The Growth of Machining Research in Great Britain

It is hardly necessary when addressing a gathering of production engineers to point out that the development of cutting tools and machine tools has contributed more to raising our material living standards during the past 30 years than any other single factor. It is, therefore, surprising to find that organised research in Great Britain was virtually non-existent until the end of the Second World War.

The only notable attempt to undertake co-ordinated research prior to the War was that of the Cutting Tools Research Committee of the Institution of Mechanical Engineers. This Committee issued its first batch of reports in 1925. These were followed by occasional reports, the last of which appeared in 1932.

About 1945 a substantial increase in machining research occurred and the foundations were laid for serious and systematic full-time work. The Institution of Production Engineers were in the lead on this occasion and promoted work at Loughborough College under the direction of the late Dr. Schlesinger. This was the origin of what is now the active organisation known as the Production Engineering Research Association which has its laboratories at Melton Mowbray. P.E.R.A. has done excellent work, along with other organisations, to transform metal cutting from an art into at least an ordered technology.

More recently, the Mechanical Engineering Research Board of the Department of Scientific and Industrial Research has set up at East Kilbride some new laboratories. Here, a small section has been established for conducting fundamental enquiries into the nature of the cutting process.

Several technical colleges have contributed to the study of machining since the War and have been responsible for a considerable portion of the total effort. At the College of Technology in Manchester, research has been conducted by Wright Baker and by Bisacre and his associates. At the Royal Technical College in Glasgow, Stabler has contributed considerably to the knowledge of chip flow. At the Cranfield College of Aeronautics, there is a well-equipped metal cutting laboratory where work is carried on by Cherry and Purcell assisted by their Diploma students.

In the industrial field, more firms are establishing sections for testing the various aspects of the cutting process. At the end of the last War, The Birmingham Small Arms Co. Ltd., decided that a systematic study of the technology of the machining of metals was long overdue and vital to further progress. A well-equipped laboratory was built at the works of B.S.A. Tools Ltd., Birmingham. This laboratory, which has already made a contribution by published work on machining, will be described in some detail later.

A metal-cutting laboratory has been equipped at the Research Department of Metropolitan-Vickers Ltd. at Manchester. It was here that Arnold made his study of the vibration of cutting tools. The mechanism of crater wear of carbide-tipped tools was studied by Trent at the works of Hard Metal Tools Ltd. in Coventry. Shell Research Ltd., at Chester, have a small section, the principal object of which is the evaluation of cutting-fluid effectiveness.

In spite of the post-war interest in machining, it will be agreed that machining research still represents only a modest effort relative to its importance. Compared with the many years that machining has been practised, machining research is a comparatively young activity conducted in but few centres of research. Nevertheless, some valuable knowledge has been obtained on the design and operation of small tools, on machine tools and the cutting fluids used. It is from this standpoint that the authors are attempting to contribute to this Conference.

2. The B.S.A. Group Machinability Laboratory

For the benefit of those who are not familiar with machining research, a brief description of the functions and equipment of the B.S.A. Group Machin-

D. A. Oliver, C.B.E., M.Sc.(Eng.), F.I.M., Director of Research, B.S.A. Group of Companies. Engineer, metallurgist and physicist. Obtained Internal Degree of B.Sc.(Eng.) with First Class Honours in 1928 in the University of London and later M.Sc.(Eng.) for post-graduate research. In 1923 joined the National Physical Laboratory and subsequently, in 1929, the Research Laboratories of the General Electric Company. From 1934 - 1944 was Director of Research at William Jessop & Sons Ltd., Sheffield. In 1944 appointed Director of Research of the B.S.A. Group of Companies.

From 1951 - 1953 was Metals Economy Adviser to the Ministry of Supply and Ministry of Materials. Was created C.B.E. and awarded the Coronation Medal in 1953.

Mr. Oliver is a Past President of the Society of Instrument Technology and a Past Vice-President of the Institute of Physics. He is a Fellow of the Institute of Physics and of the Institution of Metallurgists ; a Member of Council of the Iron and Steel Institute and Chairman of its Publications Committee. He is also a member of the Mechanical Engineering Research Board and Chairman of their MF/MS Committee dealing with problems in plasticity and the machine shaping of materials.

Mr. D. A. Oliver

Mr M. D. Kinman

M. D. Kinman, B.S.A. Group Machinability Laboratory. Has been with the B.S.A. Group since 1937. Joined as a Tool Engineer and has since served in various capacities connected with tool engineering and small tool manufacture. Is now engaged in Machinability Research for the B.S.A. Group.

T. S. Lister, B.Sc., A.I.M., Chief Metallurgist, B.S.A. Tools Limited and Research Manager of the B.S.A. Group Machinability Laboratory.

In 1942 graduated in Metallurgy at Manchester University and subsequently held appointments as Assistant Metallurgist with David Brown and Sons (Huddersfield) Limited and B.S.A. Tools Limited before becoming Technical Adviser to High Grade Steels Limited in 1950. From 1951 - 1955 was Chief Metallurgist of the Machine Tool Division of Wickman Limited.

Mr. T. S. Lister

Mr. D. Fitzgeorge

D. Fitzgeorge, Ph.D., A.M.I.Mech.E., B.S.A. Group Research Centre and B.S.A. Group Machinability Laboratory.

Served an apprenticeship with Pegler's Limited of Doncaster, brass founders and valve manufacturers. During the War served five years in the Royal Engineers and R.E.M.E. After studying at Nottingham University for a B.Sc. degree, became assistant to Professor J. A. Pope and carried out research on diesel engines of the ship propulsion type. The M.C. James Medal of the North East Coast Institution of Engineers and Shipbuilders was recently awarded to them for a joint Paper read before that Institution last February. In 1954 took up present senior staff position in the B.S.A. Group Research Centre.

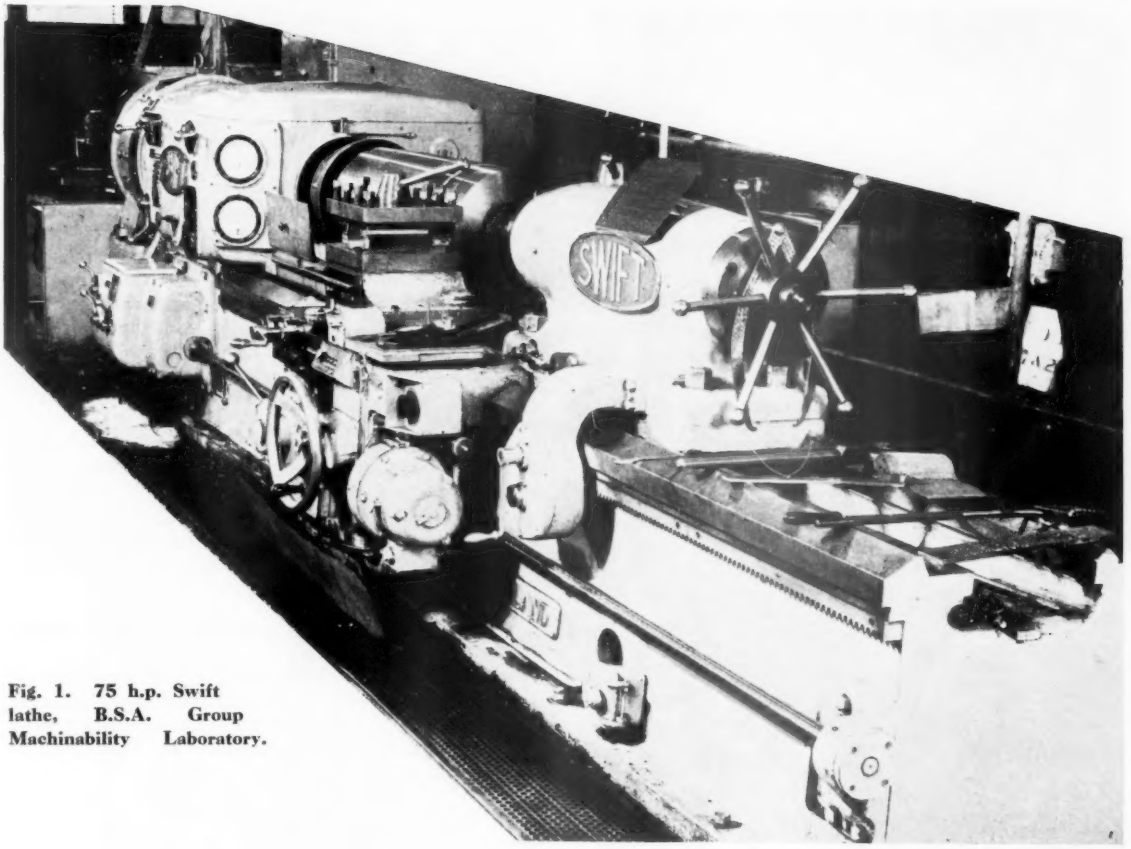


Fig. 1. 75 h.p. Swift lathe, B.S.A. Group Machinability Laboratory.

ability Laboratory will be given. The purpose of the Laboratory, which has been described in greater detail elsewhere, is to serve in every way possible the B.S.A. Group of Companies in matters concerned with machining. Consequently, its activities are quite varied.

In fulfilling its purpose, the Laboratory is not regarded as a separate and detached entity; it is a part of the larger concept of the B.S.A. Group Research Centre on which it can call for services outside its own capacity. It works in close co-operation with the Metallurgy, X-ray and Chemistry sections of the B.S.A. Tools Ltd. Laboratory, which is housed within the same building.

The principal tests carried out concern the work-piece, the tool and the cutting fluid. In the main, the demand is for tool and cutting fluid tests. Work-piece tests are sometimes required and, although they are not frequent, they are normally lengthy and difficult, involving the re-design of drills, taps and other types of cutters.

Close contact is maintained with the leading suppliers of cutting fluids, and routine testing of newly developed fluids is carried on, the results being circulated within the Group.

Investigations are also carried out on behalf of outside organisations on specific problems in metal cutting, tool development and on the effectiveness of cutting fluids. The advisory service of the Laboratory is available to many outside organisations.

Much attention has been paid to equipping the Laboratory with the best possible machines for testing purposes. Suitable machines for this type of work are rare, and the main difficulty is to obtain equipment with which satisfactory testing conditions can be achieved and which at the same time provides a sufficiently close relation to normal production conditions. The principal lathe in the Laboratory, made by Swift of Halifax, has a 12 foot-long bed and a $12\frac{5}{8}$ inch centre height. It is powered by a 75 h.p. motor which, by electric control and a gear box, gives continuously variable speeds in the range 17-2,000 r.p.m. The standard steel test billet weighs $1\frac{1}{4}$ tons and is initially 16 inch diameter and 4 feet long. A general view of the lathe is given in Fig. 1 and a close-up of a partly machined billet in Fig. 2.

Tests on large drills are made on a specially designed Adcock and Shipley drilling machine which is shown in Fig. 3. The drilling spindle is rotated by a 40 h.p. motor, giving about 460 speeds from 30 to 1,350 r.p.m. A 2 h.p. motor provides the feed, which may be chosen from 578 alternatives between 0.8 and 65 inches per minute.

There are two milling machines, one of which is

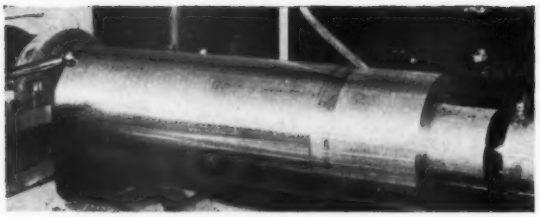


Fig. 2. Steel test billet in 75 h.p. Swift lathe.

shown in Fig. 4 and a No. 3 Huller Tapping Machine (Fig. 5). In this last photograph, the tapping machine has mounted on it a medium-capacity dynamometer for measuring and recording tapping torque. The dynamometer, which was designed and made in the Laboratory, was initially intended for drilling, and therefore is capable of measuring and recording axial thrust as well as torque.

Small drills may be tested on either of two available Pollard " Corona " type drilling machines. One is hand fed and has spindle speeds up to 6,000 r.p.m. The other is shown in Fig. 6, which shows the

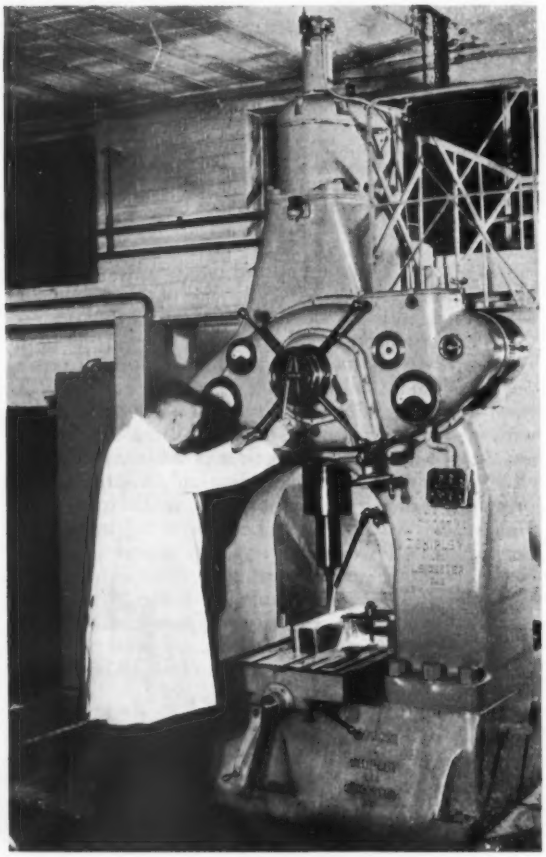


Fig. 3. 40 h.p. drilling machine.

hydraulic feed attachment. Thirty-seven speeds are available ranging between 146 and 3,620 r.p.m. A useful attachment is fitted to the table for traversing the billet to a new position after drilling a hol· (see Fig. 7).

Fig. 8 shows the outside appearance of a smaller drill dynamometer capable of measuring torques up to 3 lb. ft. and thrusts up to 250 lb. M ve nent of the work table (which is restricted to the minimum measurable amount) relative to the base, occurs only as a result of the flexure and torsion of structural members within the instrument, and this eliminates frictional errors. Fig. 9 shows the apparatus used for calibrating the dynamometer. Besides the equipment briefly described above, the Laboratory includes other ancillaries, such as point grinding machines for drills and for lathe tools, and drill point measuring apparatus.

A vital part of the equipment of a laboratory, which might escape notice if not specifically mentioned, is the accumulated experience of the staff. This is not an easy quantity to assess, but if it exists in good measure, it is equivalent to (and possibly more effective than) a considerable amount of statistical planning and test work.

3. Present State of Knowledge of the Cutting Process Reviewed

The way to a new understanding of the machining process was paved by Ernst and Merchant[2,3] working in America in the late 'thirties. The development of a quick-stopping technique opened up a new field of study in the mechanics of chip formation, and allowed chips to be sectioned after the cutting action had been stopped in a few micro-seconds. Prior to the development of this technique, sectioning had given a false indication of chip geometry, since the observed section occurred at the end of a relatively long deceleration period.

Using this new technique, it was possible to classify chips into three groups: " discontinuous," " continuous " and " continuous with built up edge." The continuous chip is the most common and was the first to be analysed by Merchant. An almost-identical analysis was published in Finland somewhat in advance of Merchant's by Piispanen.[4] This fact was not revealed until after the analysis had become generally known as Merchant's theory.

The first part of the analysis is a study of the forces acting on a sharp tool (i.e., one with no flank wearland), and has been found to be very useful. The main objections to Merchant's analysis relate to the second part in which he attempted to derive a relation between the true rake angle, the shear angle and the friction angle at the chip-tool interface. The objections are to the minimum energy hypothesis and the adoption of Bridgman's relationship for the shear strength of the metal as affected by normal compressive stress.

Following the work of Merchant, there has been a spate of published work on various aspects of the machining process. Dealing with the mechanics of chip formation is a paper by Shaw[5] who uses the argument that metal contains " weak spots." For the purpose of his argument, he assumes these to have

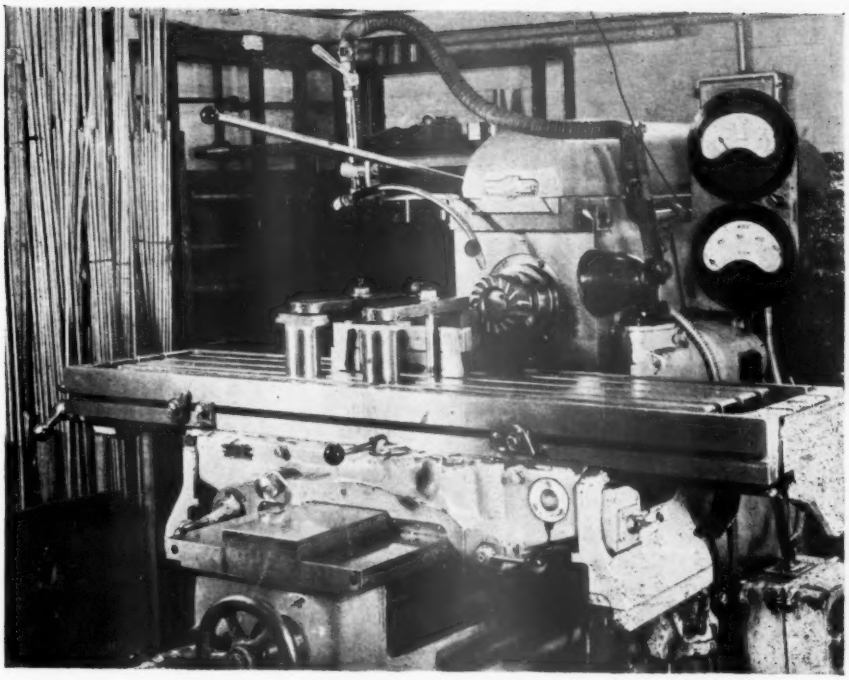


Fig. 4. Milling machine.

an orderly array with a suitable orientation within the metal. On this basis he explains mathematically why a shallow cut requires a greater amount of energy per unit volume of removed metal than a deep one. He also assumes an idealised work-hardening diagram for the metal and shows that work-hardening affects the process. At the same time, while not claiming to do so, he virtually disproves the Bridgman relationship adopted by Merchant. Shaw and his associates also show that for very small depths of cut the shearing stress approaches the theoretical strength of the metal. This fact is useful not only in machining, but also in the study of metal physics.

More recently, Lee and Shaffer[6] have produced an analysis based on the theory of plasticity which considers the stress field within the chip in the vicinity of the shear plane. Their analysis was extended to include the case where a built-up edge was present.

Hill[7] has recently suggested a new approach to the problem of the more precise determination of the mechanics of machining. He claims that the search for a unique solution is " fruitless," since there may be many, possibly an infinite number, of steady-state chip configurations of the shear plane type. The initial conditions must influence the ultimate steady state. Hill claims that previous theories do not agree well with experimental results, but while he suggests the basis for a new theory, no complete new theory has, as yet, been advanced. Goddard[8], on the other hand, in a work which has not been generally published, states that pressure and friction on the flank wear-land are the main factors which upset the agreement of experimental results with Lee and Shaffer's equation. His own results, in which the flank wear effect is nullified by extrapolation to zero-wear conditions, are claimed to be in excellent agreement.

A close link exists between the Plasticity Division at M.E.R.L. and Hill, whose recent paper has already been mentioned. The Division is in agreement with Hill on the unsatisfactory nature of current theories of the mechanics of the cutting process. An experimental study of the modes of plastic deformation in the cutting process has been carried out there using the gridded-specimen technique as a preliminary to trying to find a more satisfactory solution to the problem (Fig. 10). This study is intimately linked up with a current investigation of the important factors in the machinability of metals. Here, by measuring the cutting forces and the chip geometry, a study is being made of the influences of such factors as the friction between the metal cut and the tool material, lubricants, the strength of the metal and its capacity for work-hardening, the temperatures generated in the process and the formation of the so-called built-up edge. The conditions under which metal is plastically deformed in the cutting process raise questions of fundamental interest concerned with the mechanism of plastic deformation, which are also being studied in the Plasticity Division M.E.R.L.

The steep temperature gradients in the cutting process make a realistic experimental study of the temperature distribution in cutting very difficult. An analytical approach has been made, using relaxation

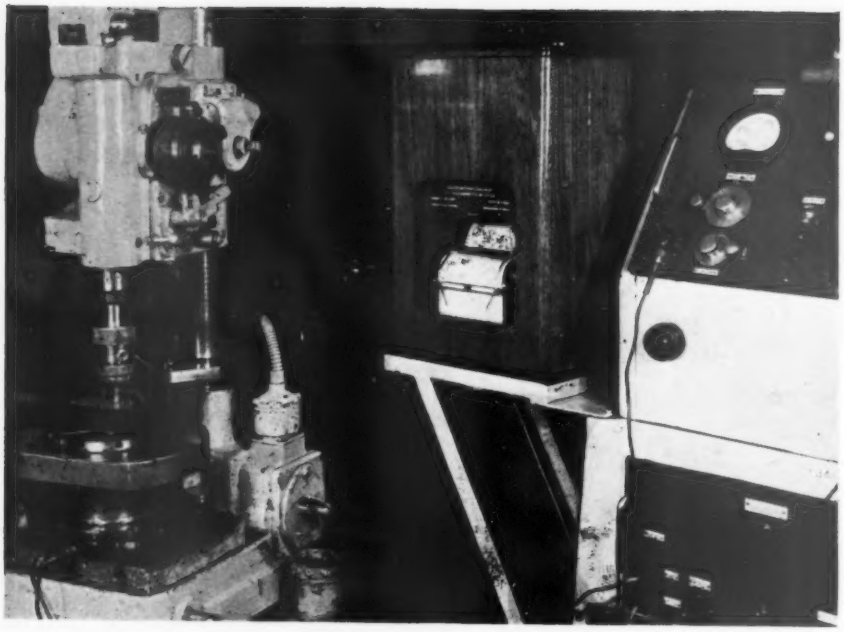


Fig. 5. Tapping machine, with torque and thrust dynamometer and recording apparatus.

methods, which makes it possible to estimate the approximate temperature distribution in the chip, workpiece and cutting tool when the tool is sharp (Fig. 11). Experimental work has shown that in addition to the heat sources along the shear plane, and at the chip-tool interface, the frictional heat source at the flank of a worn tool is sufficiently large to be of significance in estimating the temperature distribution in cutting. The results of these studies of the mechanics of the cutting process and of the temperature distribution in the cutting process are being employed to determine the dependence of the rate of wear of cemented carbide cutting tools on friction, contact pressures and the temperatures at the wearing surfaces, in order to discover the factors of importance.

The analysis of the mechanics of chip-formation is hampered by lack of knowledge of the properties of material at the very high strain rates and pressures involved, and of friction between metallic surfaces under very great pressure at high temperature. Some progress has been made and there is always the hope that some basic knowledge will be uncovered which will greatly simplify the machining process. However, it would appear that there is a decline in interest in this branch of the subject in favour of a more practical study of the factors giving better tool-life, and better surface finish. Now even Merchant[9] himself, whose name has been prominent for 15 years or so in connection with the fundamental mechanics, has chosen to pioneer the assessment of tool-life using radioactive isotopes, and is studying the alloying properties of metals which are customarily paired in the cutting process. The Authors, while themselves committed to a practical approach to machining research, would not advocate the discontinuation of chip-formation studies, and consider it appropriate that the study is continuing at M.E.R.L., Nottingham University and elsewhere.

Chip and tool temperatures are important in connection with tool-life, since the exposure of the tool tip to excessive temperatures will lead to softening and rapid wear. The high temperatures are the result of metal deformation at the shear plane and friction at the face and flank of the tool. Estimates based on the energy input and the physical constants of the workpiece material suggest that the chip will reach a maximum temperature of about 500°C. At high cutting speeds, almost all the heat remains in the chip and it is argued that variations in cutting speed will not affect the temperature appreciably, since the higher speed will result in a greater amount of energy being supplied to a proportionately longer chip in a given time. An increased feed, however, will require a reduction in cutting speed for the same tool life. The accepted relationship for these quantities is:

$$V = \frac{C}{T^n d^x f^y}$$

where V is the cutting speed (ft./min.), C is a machining constant, T is the tool life (min.), d is the depth of cut (in.) and f is the feed per revolution (in.). Boston[10] has determined that for many cutting operations n is about 1/6, and average values for x and y are about 0.37 and 0.77 respectively. This equation shows that for a given life of the tool, a low cutting speed, a large feed and a large depth of cut will give the best material removal rates, but practical limits exist in the power available, the strength and stiffness of the machine, the tool and the workpiece and the quality of the resulting surface finish.

For machining steels of medium tensile strength, particularly with high speed tools, a good quality soluble oil is generally adequate as a cutting lubricant. This is particularly so in the case of milling, as the interrupted cut gives the cutting edge time to cool and also for a film of lubricant to be re-formed on the cutting face. As the tonnage of the steel increases, or alternatively, additional elements which increase the work-hardening properties of the material are added, more effective cutting lubricants should be used. A stage is reached when a cutting lubricant with the activity carefully balanced to meet the needs of the job is absolutely necessary to enable the material to be machined at all, regardless of any question of a higher rate of production.

Active cutting lubricants have been found to be helpful when using carbide tools on difficult materials, but their use is restricted mainly to drilling operations when the power consumption is relatively low and there is therefore no great amount of heat generated which would destroy the characteristics of the oil and cause unpleasant fuming. Mildly active soluble oils can be used to advantage with carbide tools which are affixed to their holders by brazing, to keep the temperature of the cutter body down to a level where there is no danger of the brazing becoming weakened. Spray or mist cooling is advantageous in these cases as it avoids the use of a large volume of cutting fluid.

Whilst it has long been appreciated that the indentation (e.g., Brinell) hardness of a material does give a rough and ready measure of its machinability, it is now accepted that there is no direct correlation between the two properties, and that any study of the machining properties of a material must be accompanied by a full investigation of its more fundamental metallurgical characteristics. Of first importance is the microstructure, which in turn must be studied in the light of the chemical composition of the material and its thermal history. Whilst claims to predict machining characteristics from microstructure alone are to be viewed with reserve, this form of examination is the most valuable in assessing machinability. Experience in the Authors' laboratory[11] has also proved the value of microradiography in cases where variations in concentration of a solute element (e.g., manganese in steel) affect machining properties, but are undetectable by conventional microscopy. Details of the steel-making process, and of subsequent mechanical and thermal treatments, are also relevant to a study of machining characteristics.

Metallurgical steps that can be taken to improve machinability are of two kinds: first, the addition of elements to promote free machining properties, and secondly, special heat treatments. The addition of lead to alloy constructional steels and of selenium to certain stainless steels are examples of the first type; and the controlled annealing of low carbon alloy steels to give block ferrite is an example of the second.

Summarising this brief review of machining research, it becomes clear that the chip-photography technique of Merchant and Ernst has provided us with a very clear picture of the cutting process which should form a background for everyone interested in its development. The fundamental investigator, however, who seeks a mathematical basis and rigid

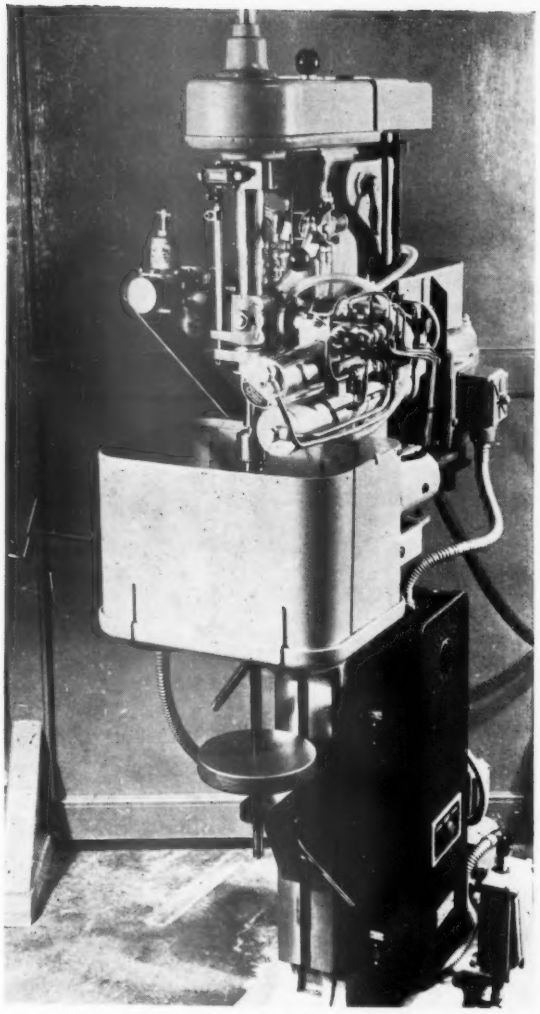


Fig. 6. Small drilling machine.

Fig. 7. Small drilling machine ; test billet traversing device.

Fig. 8. Small drill dynamometer and test piece.

correlations is at a serious disadvantage compared with the person whose duty it is to develop specific factors such as quality of tool tip, effectiveness of cutting fluid, and structure of workpiece. It is along these last indicated lines that the improvements of the last 30 years have taken place.

4. Machining Problems Peculiar to the Aircraft Industry

In fields other than aircraft production, it has been found profitable not to design a component entirely from a functional point of view, but to include, at the design stage, consideration of how the component may most conveniently be made; that is, the product is designed around the process. The new requirements of aircraft manufacture demand that this principle be abandoned. The aerodynamic and structural requirements are dominant ,and for their realisation it is imperative that the machining ability, if not already in existence, be developed to the required level.

The design of new high-speed aircraft is forcing the aircraft industry towards two well defined machining problems. Higher flight speeds demand greater chord : thickness ratios for wing sections and a material which will retain its strength when kinetic heating is effective. These requirements lead naturally to integral construction methods and the use of other metals than light alloy for airframe members. The metals chosen as alternatives are high tensile steels, stainless steels and titanium alloys.

The rate of application of titanium alloys to aircraft production has not been as high as some of the early predictions. In the U.S.A. the reasons have been partly technical and partly due to the lengthy periods needed for full prototype testing. In Great Britain, it has taken time to build-up and develop the necessary titanium metal extraction plant and the specialised melting furnaces, but by late 1956 we should have mounting domestic production. Some authorities have predicted that airframe makers will by-pass titanium alloys and move directly from the stronger aluminium-based light alloys to the high tensile and ultra-high tensile steels. Ultra-high tensile steels are being developed currently for use as spar-root fittings, these being forged and subsequently machined. High tensile steel forgings, subsequently machined, are also being used in undercarriages. These new departures present difficult problems in the machining of deep pockets of complex shape. Difficulties arise in the supporting of such workpieces for the machining of thin webs when the tool forces are great, as in cutting ultra-high tensile steel. It may be that high positive rake machining, which will be discussed later in the Paper, will help in this respect by reducing tool forces.

Turning and particularly milling are the operations most needed in airframe construction. There are possible uses for broaching, but the high cost of broaches reckoned against the small numbers of parts required is a disadvantage, particularly as design modifications are continually being made, and manufacturing procedures must be flexible.

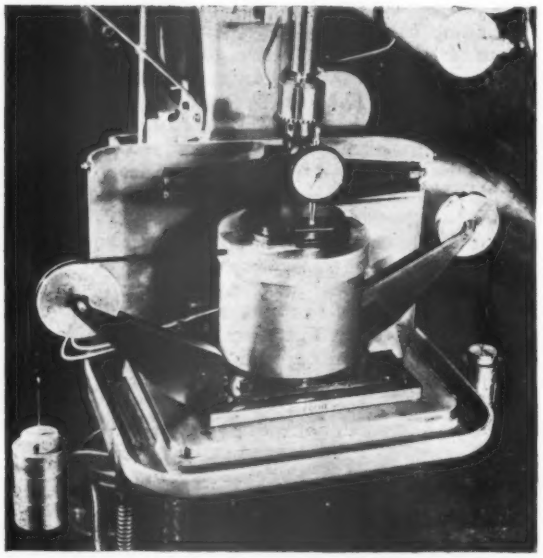


Fig. 9. Small drill dynamometer ; thrust and torque calibration arrangements.

5. The Materials For Airframe Construction

It is not intended to include here a comprehensive list of the many materials which are used or are being considered for use in airframe construction. Only those materials will be referred to which are of particular interest in connection with machining difficulties, or which are novel in some respect.

Aluminium alloys are used more than any other material at present. The majority of such alloys present little difficulty from the point of view of machinability, though this is not to say that in practice difficulties do not occur, due to the size, shape and complexity of the parts called for. Problems associated with the actual cutting process do, however, occur in the modern high strength alloys, as represented by the Zn-bearing-types (D.T.D. 363A and 683) and the Super-Duralumin alloys (L.64-65 and 70-73). The compositions and properties of these alloys are briefly outlined in Table 1.

The other materials now coming into use in airframe construction are high tensile steels and titanium alloys. The extent to which they will be applied depends partly on development of types having favourable strength to weight and strength to rigidity relationships, and partly on the ease, or difficulty, with which they can be manipulated. Table 2 shows an interesting comparison between the three classes of material.

Whichever criterion is used, it is clear that so far as room temperature properties are concerned, the airframe designer's interest in titanium alloys commences at a strength of about 60 t.s.i. and in steels about 100 t.s.i. Less-strong materials may be useful in structures experiencing any marked temperature increases, since it is well known that the elevated temperature properties of titanium alloys and particularly of steels are better than those of precipitation-hardened aluminium alloys. Further discussion of this question is outside the scope of the present Paper, and we shall now briefly consider the properties of the titanium and iron-base materials available.

Titanium alloys fall into two main groups, according to their microstructure. Pure titanium has the hexagonal close-packed structure (denoted by 'alpha') and alloying elements such as aluminium, zirconium and tin, besides oxygen and nitrogen, which are soluble in this structure, produce the so-called alpha alloys. The limiting tensile strength for this type of alloy is about 60 t.s.i., and a typical alloy is one containing 5% Al and 2% Sn. Alloys containing deliberate oxygen additions have been developed, but are being abandoned in view of the disproportionate embrittling effect of oxygen. Nitrogen, above a certain quantity, also embrittles titanium alloys.

Many alloying elements, notably molybdenum, vanadium and niobium, stabilise the beta phase

TABLE 1

Composition and Properties of Some High Strength Aluminium Alloys

Type (Comp. Wt. %)	D.T.D. 363A	D.T.D. 683	L. 64	L. 65	L. 70	L. 71	L.72 (Clad)	L.73 (Clad)
Zn	4.0/8.0	4.5/6.5			0.2			
Cu	3.0	1.5			3.8/4.8			
Mg... ...	4.0	2.0/3.5			0.55/0.85			
Mn ...	1.0	0.25/1.0			0.4/1.2			
Cr	1.0	(0.5)			0.3			
Fe	0.6	0.5			1.0			
Ti	0.3	(0.3)			0.3			
Si	—	0.5			0.7/0.9			
Ni	—	—			0.2			
Condition	S.T.A.	S.T.A.	S.T.R.	S.T.A.	S.T.R.	S.T.A.	S.T.R.	S.T.A.
Typical Properties	Bars	Bars	Bars	Bars	Sheet & Strip	Sheet & Strip	Clad Sheet & Strip	Clad Sheet & Strip
0.1% Proof (t.s.i.)	33	30	15	26	16	23	15	21
U.T.S. (t.s.i.)	38	35	25	30	26	28	25	27
Elong. % ...	5	10	15	8	15	8	15	8

Note.—Single figures are maxima. Bracketed figures are optional.
S.T.A.—Solution treated and preciptation hardened.
S.T.R.—Solution treated and room-temperature aged.

TABLE 2

Comparative Properties of Aluminium Alloys, Titanium Alloys and Steel

Material	Density (g./ml.)	Young's Modulus (room temp.) (p.s.i.)	Required Strength to be equivalent to 35 t.s.i. Al. alloy on basis of:—	
	(circa)	(circa)	Strength/ Weight	Strength/ Rigidity
Al. Alloys ...	2.7	10×10^6		
Ti. Alloys ...	4.5	17×10^6	58 t.s.i.	60 t.s.i.
Steel	7.8	30×10^6	101 t.s.i.	105 t.s.i.

TABLE 3

Mechanical Properties of Titanium Alloys

(by the courtesy of Messrs. William Jessop & Sons Ltd.)

Composition	Hylite Code No.	Type	0.2% Proof Stress t.s.i.	U.T.S. t.s.i.	Elongation %	Hardness: Brinell
Commercially pure Ti	10	Alpha	25	34	25	130
5% Al., 2½% Sn....	20	Alpha	52	60	15	320
2%Mn., 2% Al. ...	30	Alpha-beta	36	44	20	230
4% Mn., 4% Al. ...	40	Alpha-beta	55	63	15	310
Complex Al. Alloy.	50	Alpha-beta	65	75	15	350

TABLE 4

Composition and Mechanical Properties of High Strength Wrought Steels (S. Series)

Specification	Composition	0.1% Proof (t.s.i.)	U.T.S. (t.s.i.)	Elongation (%)	Impact Value (ft. lb.)
S.97	2½% Ni-Cr-Mo ... (0.27-0.35% C.)	54	65-75	16	35
S.98	2½% Ni-Cr-Mo. ... (0.36-0.44% C.)	65	75-85	14	25
S.99	As S.98	70	80-90	14	25
Draft	Probably Cr,Mo-V or Ni-Cr-Mo-V. ...	—	100	—	—

(body-centred cubic structure) and the majority of commercial alloys have a mixed alpha-beta structure. The proportions of the two phases vary with temperature, so that the alloys are amenable to heat treatment. Typical alloy combinations are aluminium-vanadium and aluminium-manganese, and strengths approaching 70 t.s.i. have been achieved. Table 3 gives the mechanical properties of a number of titanium alloys.

Very high tensile steels can be produced either by hardening and low-temperature tempering, or by cold working. The former type may be used for complex forgings and other parts made from wrought steel, the latter in the form predominantly of cold-rolled sheet.

The compositions and properties of steels from 65 tons upwards are given in Table 4. Very little work has been done on the machining of these steels.

One or two aircraft firms have been supplied with samples of steel to S.99 specification and are attempting to find suitable machining methods. It would be preferable to machine completely in the softened condition. The parts are however complicated and large, and therefore very difficult to harden without cracking or at least badly distorting. Moreover, grinding after heat treatment to reduce to finished size has even worse problems than actual machining.

6. The Influence of the Machine Tool on Metal Cutting Operations

The remarks in this section refer principally to milling operations. As has already been stated, it is in this field that airframe producers are particularly interested.

Most British milling machines have been developed for use with high speed steel cutters and since the introduction of carbide-tipped cutters some may have been found to be insufficiently rigid. The aircraft industry is probably the principal advocate of carbide-tipped cutters for milling and it may be that millers are being used which, while giving reasonable cutter life with H.S.S., are incapable of providing the necessary conditions required for successful cutting with carbide.

When cutting tools are put to severe use, either by machining difficult materials or by high metal removal rates, tool-life is very much dependent on the design and condition of the machine used. This is particularly noticeable with carbide tools on intermittent cutting of high tensile steels. Best results are obtained on conventional machines when working at a fraction of full capacity.

If such a machine is worked to its full capacity, tool-life may be very short, even though external appearances suggest a satisfactory cutting operation, free from chatter. Poor tool-life under such conditions is frequently attributed to poor quality cutting tools, when the actual cause lies in the machine. Transferring the job and the cutter to a larger machine in such a case will invariably lead to better cutter performance.

An empirical law connecting speed, feed and depth of cut with tool-life has been quoted earlier in this paper. The validity of this law is governed by the following factors, whose effect is greater than the mere modification of the value of the constant C:—

(i) Cutter design.
(ii) Adequacy of cutting fluid or lubricant supply.
(iii) Effectiveness of cutting fluid or lubricant.
(iv) Rigidity of machine and set-up.
(v) Freedom from backlash of work table and spindle drive.
(vi) Clearance and imperfections in bearings.
(vii) Smoothness of operation.

For every type of material there is a minimum standard for each of these factors. Below this results will be poor, scattered or even impossible to obtain. The tougher the material the higher the standard required.

In a publication of the Institution of Production Engineers, Galloway[12] has indicated the need for the scientific design of bearings, spindles and other machine members to minimise tool deflections under load. The present Authors would emphasise that machine deflections, as well as causing inaccuracy and poor finish, also account for poor tool-life—a fact which is insufficiently well known.

Although the present Paper can do little more than repeat the need for a detailed scientific study of machine design, brief mention may be made of a few relevant points. Knee-type millers are inferior to those in which the table is supported by a long fixed bed. In cases where the knee-type construction must be retained, then there should be a substantial increase in the length and spacing of the vertical and transverse slide ways to increase work-table stability.

Cutter arbors and arbor supports are a weak point in conventional milling machine design and lead to intolerable deflections when cutting tough materials. Arbor diameters should be increased and arbor lengths effectively reduced, wherever possible. Distance collars are only fully effective in increasing flexural stiffness when considerably pre-stressed in compression. Means of ensuring an adequate value of pre-stress in the collars would be helpful. The cantilever principle for arbor supports, while making for easy manipulation, is basically unsound and should be abandoned in favour of more rigid designs. It would be an improvement if the keyway in the arbor shaft could be eliminated and replaced by some other method of locking the cutter. The keyway destroys the rotational symmetry of the arbor and varies the cutter deflection according to its angular position, causing a periodic chatter and surface markings. Bearing deflections contribute to the deflection at the cutter. Bearings should be free from clearance at all working speeds. They should be of the ball or roller type and pre-loading is essential.

Increased attention should be paid to the design and lubrication of the feed mechanism and slideways to promote smooth action. Backlash eliminators, particularly in the table feed, should be improved since they are sometimes the cause of chatter when climb-milling.

In some cases it may be advantageous to employ spheroidal graphite cast-iron or steel in place of the more usual grey cast-iron, even though this will sacrifice some damping capacity. The advantage is in the higher elastic modulus of these materials.

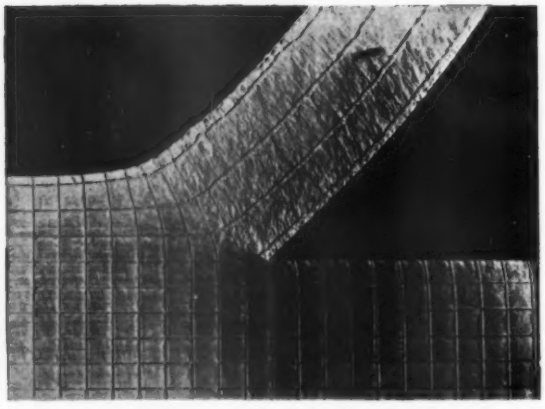


Fig. 10. Deformation pattern obtained when cutting lead (tool rake angle + 45°, speed 0.215 f.p.m., chip thickness 0.150 in., grid size 0.05 in.

(Mechanical Engineering Research Laboratories, East Kilbride)

At low stresses, such as might occur in machine beds and bearing housings, the elastic moduli (E) are approximately:

Steel	30×10^6 lb./sq. in.
S.G. iron	26×10^6 lb./sq. in.
Good commercial quality grey iron	20×10^6 lb./sq. in.

Whichever material is used, however, it is most important that the material is used to the best possible effect. Strength and rigidity are not only achieved by large masses of material, and much will be gained by balanced structural design.

7. Recent Tests on the Cutting of High Tensile Steels

Some recent tests have been carried out by the Authors on alloy steel billets heat treated to tensile strengths of 100 and 95 t.s.i. The respective analyses (wt. per cent.) of the two materials used were as follows:—

	100 *t.s.i.*	95 *t.s.i.*
C	0.36	0.34
Mn	0.69	0.51
Ni	0.75	4.12
Cr	3.21	1.21
Mo	1.04	0.29
V	0.27	—

It was found that when using carbide face mills with a cutting speed of 140 f.p.m. and a feed per tooth of 0.004 to 0.005 in., a satisfactory tool life could be obtained provided the work-piece and cutter were rigidly mounted. Tool geometry is important. It is essential that the cutting edge is a straight line to allow the chip to curl easily. There should be no radius or chamfer at the nose, and the resulting sharp corner should be rendered less acute by a substantial approach angle (40° to 45°). A touch with a diamond hand-lap on the sharp corner is advisable to remove any loosely held grains of carbide which may be present. The best results have been obtained with positive maximum rake angle. The cutting edge is made oblique to the direction of cutting to increase the rake in a radial, and decrease it in an axial, direction.

A cutter such as that described is successful except when used under "up-milling" conditions. No success has been achieved with up-milling using carbide-tipped cutters on these high tensile steels.

A recent strikingly successful example of slab-mill performance on 80/90 t.s.i. steel has been provided by Messrs. Wickman Ltd. Using a helical carbide-tipped slab-mill 3 in. dia. × 5 in. long with 6 teeth, a total of 240 in. of the material was cut in six passes, three at a depth of cut of 0.080 in. and three at a depth of cut of 0.100 in., with negligible wear of the cutter. It is emphasised that this impressive result was only made possible by the use of a horizontal miller of exceptionally stable design. The cutting speed for each pass was 440 f.p.m., and the tooth load, measured in a direction parallel to the table movement, was 0.0089 in. Cutter angles were as follows:—

Radial Rake	0°
Primary clearance angle	9°
Secondary clearance angle	28°
Helix angle	20° R.H.

An excellent surface finish resulted.

The Authors have recently briefly investigated the effects of machine and set-up stability on carbide-tipped cutter performance. It was found that an 8 in. dia. face-mill which had given a satisfactory performance when mounted directly on to the spindle nose of a horizontal milling machine, gave a poor performance when mounted on a 2 in. dia. arbor on the same machine. It is interesting to note that this early failure of the arbor-mounted cutter was not accompanied by any observable chatter. Similar examples as between the performance of one milling machine and another have also been experienced.

In spite of the promise shown recently by carbide cutters as described above, the conditions for success are undoubtedly critical and sometimes unattainable, as, for example, in cases where climb-milling is not possible. It is therefore clear that high speed steel cutters will not be displaced over a large part of the field. The Authors have accordingly started work with high speed steel cutting tools which is intended to supplement the work of Cherry[13] who found that when cutting steel to specification D.T.D. 331 (100 t.s.i. approximately) the tool life increased as the rake angle increased to 15° positive, but thereafter diminished. The present Authors' tests yielded the following results:—

Cutting Speed: 60 f.p.m.
Feed: 0.0033 in. per rev.

Rake angle	*Tool life (min.)*
15°	36.2
30°	12.8 }
	30.0 }
35°	51.4
40°	90.3

These figures show that increasing the rake angle beyond 30° leads to a rising trend in tool life.

Using tools with rake angles between 5° and 10° it is known that very low cutting speeds (less than 25 f.p.m.) are required, and active straight cutting oils give the best results. The Authors have found that if the rake angles are considerably increased to 35° or 40°, much higher cutting speeds are possible, providing the feed is relatively fine (0.002 to 0.003 in. per tooth) and that the cutting edges are adequately cooled by either a copious supply of soluble oil or by " mist " cooling. Straight cutting oils are ineffective under these conditions.

Tools have been tried made from straight 18% tungsten; 18% tungsten with 10% cobalt; and 14% tungsten with 4% vanadium high speed steels. The first type of high speed steel is tough, the second has a high degree of hot hardness and the third a high degree of abrasion resistance. Using the 10% cobalt steel (which proved much the most suitable) and the high rake angles, a cutting speed of 60 f.p.m. has been found to be practicable. A straight cutting edge is again essential. Rigid workpiece and tool mounting is vital when using high rake tools if chipping of the cutting edge is to be avoided.

The above tests were conducted on the Swift lathe previously mentioned. They are now being extended to the use of high rake high speed steel fly-cutters on a milling machine. It has been found necessary to depart from the geometry of the lathe tool by increasing the approach in angle order to obtain the necessary thin chip. This fly cutter has performed successfully on the 100 ton material on the milling machine where carbide tools failed completely. Again, conventional up-milling proved unsuccessful and the necessity for soluble oil cooling, already indicated by the turning tests, was confirmed.

With this high rake type of tool, cratering does not occur, but failure ultimately results from the formation of narrow grooves across the cutting edge. This observation would suggest that when very high rakes are used tool life will be very much dependent on the presence of abrasive non-metallic inclusions in the workpiece. Attention should also be paid to the structure of the high speed steel to ensure no unnecessary loss of strength due to carbide segregation.

The effect of surface finish of face and flank as determining the perfection of the cutting edge, has not yet been investigated but it is anticipated that a fine finish will add to tool life.

8. Machining Titanium Alloys

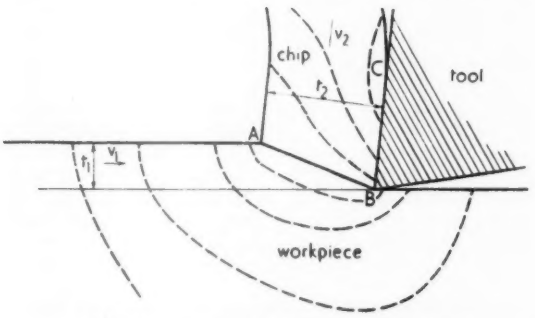
There is now a large volume of literature available on the various investigations made in Europe and America on the machining of titanium and its alloys. A good deal of the information given is now of little value since it relates to titanium alloys which have become obsolete. These were easier to machine than certain of the alloys which have taken their place. An example of the latter is the 130 AM alloy containing 4% aluminium and 4% manganese. The following remarks summarise the Authors' work on machining this alloy.

A very great amount of heat is generated during cutting, but this is not troublesome providing a copious supply of coolant is directed at the seat of cutting, in which case no special tools or techniques are required. It is essential to maintain a keen cutting edge. Permissible cutting speeds are closely related to feeds, but it is an advantage to run at the highest permissible cutting speed, since feed and permissible cutting speed do not rise and fall in strict proportion.

The drilling of small holes presents some difficulty, but the most difficult operation encountered is tapping, which has yielded only very limited success after considerable effort. The possibility of tapping this alloy depends on what is attempted; avoidance of tapping too near the full depth of blind holes and the acceptance of the minimum percentage thread depth will help considerably and may determine whether a certain tapping operation will be possible or not.

Drilling is quite feasible, and if the holes are not too small or deep, they can be drilled with standard drills when the point is thinned so as virtually to remove the chisel edge. Better performance can be obtained using drills of special design, these being necessary when drilling small holes. The drills should be very rigid, having a thick web, a short flute length and high helix angle. The point should be thinned to give the so called split-point and the rake angles made positive.

Cutting fluids with the correct properties are essential to achieve a reasonably good drill life. The necessary properties of the cutting fluid are provided by very high grade soluble oils containing extreme-pressure additives. With these fluids a cutting speed of 35 f.p.m. may be used, whereas lower grades of soluble oil will give short drill life at 20 f.p.m. Deep



Idealized model of the metal cutting process

- - - - typical isotherms.

Fig. 11. Temperature distribution in orthogonal metal cutting.

(Mechanical Engineering Research Laboratories, East Kilbride)

holes require the frequent retraction of the drill to replenish the supply of coolant at the bottom of the hole.

Unsuitable cutting fluids allow conditions which give rise to violent fluctuations in the drill torque. The fluctuations are taken as indicative of stick-slip between the chip and the tool face and occur under conditions which give poor drill life.

9. Future Requirements of the Aircraft Industry

The aircraft industry works against a continually changing background as flight development proceeds. This means that speculation is required on the forms of future aircraft, and consequently on the methods and machines which are to produce them. The Authors have gathered from many discussions the following picture of future aircraft development; wings will grow thinner relative to chord measurements; they will grow smaller; light alloy will be replaced by titanium alloys or eventually by very strong steel, and wings might ultimately disappear altogether.

This picture applies to the maximum state of development at any particular time. It is presumed that there will always be a large number of commercial aircraft made for economic reasons which will, at the date of their manufacture, be well behind the maximum state of contemporary development. This will be a comforting thought for the machine tool manufacturer who sets out to cater for the changing needs of the aircraft industry.

It would be convenient to plan for the ultimate stage of development as at present conceived. Unfortunately, that is not feasible, and we must turn our attention to the problems which are immediately ahead. We expect in a few years time to be required to machine integrally-stiffened wing skins from solid slabs of steel or to fabricate them from steel sheet, probably using welded seams. The router will not be suitable for cutting steel, and a substitute will be required. The move towards unit construction of wings requires larger tables on our machines. The frequent changing of designs of aircraft components will require our machines to be adaptable. Machining high tensile steel and other difficult materials requires close control of machining conditions; a slight departure from optimum feeds and speeds will render the operation impossible, troublesome or uneconomic. It is therefore necessary to have a greater choice of feeds and speeds on our machines. In some operations, such as facing, it will be necessary to provide steplessly-variable speeds automatically controlled. Above all there must be great rigidity and freedom from backlash in tables and spindle drives.

10. General Observations and Concluding Remarks

Following last year's conference, some criticisms were voiced against the British machine tool manufacturers. An editorial in "Aircraft Production" (February, 1955) accused them of sheltering behind full order books and ignoring the special requirements of the aircraft industry. A more balanced note has recently been struck in an editorial in "The Engineer" (December 16th, 1955) which suggests that the real culprit is the user, in the lack of advanced machine development. Has the aircraft industry stated clearly its requirements to the machine tool industry? Has it made them clear to the Ministry of Supply? The impressions gained by the Authors are that in the present development race the aircraft industry is not quite sure of what it needs, and they hope that some light will be thrown on these questions during the discussion. They also consider that the aircraft industry should be encouraged to purchase advanced prototype machine tools, so as to secure a lead on behalf of the nation.

The machine tool problem is not the only one which faces the aircraft makers. Other special equipment is required for the manufacture of newly designed aircraft. The true need appears to be for the maximum co-ordination so as to ensure that the aircraft industry receives the appropriate amount of technical assistance from other industries. It should be settled to what extent we in Britain shall develop our own machines, which firms shall undertake the development, and what machines shall be bought from abroad. Public money for development of special machines should be made available as soon as a plan has been agreed. It would appear that only in such ways will the aircraft industry in their future expansion secure the full support of the machine tool manufacturers and other industries.

11. Acknowledgments

The Authors are indebted to many in the aircraft industry and the Ministry of Supply for valuable discussions and helpful advice; to other members of the B.S.A. Group Research Centre staff, particularly Mr. E. Bishop; to Mr. L. Fine of William Jessop & Sons Ltd.,Sheffield; to Mr. H. Ll. D. Pugh,M.E.R.L., East Kilbride, for supplying details of the current work of the Plasticity Division and providing Figs. 10 and 11; and finally to Mr. H. P. Potts, Managing Director of B.S.A. Tools Ltd., for his interest and encouragement.

REFERENCES

1 Wolfe, K. J. B. and Spear, P. "The Organisation & Work of the B.S.A. Group Machinability Laboratory" The Engineer, 189, 1950: 352.

2 Ernst, H. and Merchant, M. E. "Chip Formation, Friction and Finish." Cincinnati Milling Machine Co., booklet 1940.

3 Merchant, M. E. "Mechanics of the Metal Cutting Process." Parts I and II, J. App. Phys. 16, 1945: 267-275, 318-324.

4 Piispanen, V. (1) Teknillinen Aikakanslehti 27, 1937: 315-322. (2) "Theory of Formation of Metal Chips." J. App. Phys. 19, 1948: 876-881.

5 Shaw, M. C. "A Quantized Theory of Strain Hardening as Applied to the Cutting of Metals." J. App. Phys. 21, 1950: 599-606.

6 Lee, E. H. and Shaffer, B. W. " The Theory of Plasticity applied to a problem of Machining." J. App. Mech. 18 (4), 1951: 405-413.

7 Hill, R. " The Mechanics of Machining: A new approach." J. Mech. Phys. Sol. 3, 1954: 47-53.

8 Goddard, J. " Basic Theory and Experimental Technique in Machining and the Application of Metal-Cutting Fluids." (Unpublished.) College of Aeronautics, Cranfield, Diploma thesis. 1955. (See Aircraft Production, Oct. 1955, p. 420, for summary.)

9 Merchant, M. E., Ernst, H. and Krabacher, J. " Radioactive Cutting Tools for Rapid Tool-Life Testing." Trans. A.S.M.E. 75 (4) 1953: 549.

10 Boston, O. W. " Metal Processing." John Wiley & Sons, Inc., N.Y., 1941.

11 Wolfe, K. J. B. and Robinson, I.R. "The Effect of Manganese Segregations on Machinability" Metallurgia, 43, 1951: 3.

12 Galloway, D. F. " Machine Tool Research & Development." Research Dept., Institution of Production Engineers, 1945.

13 Cherry, J. Report on the Machinability of Aircraft Steel. D.T.D. 331 (B.S.S. 99) using H.S.S. tools. Note No. 24, April, 1955. College of Aeronautics, Cranfield.

REPORT AND DISCUSSION

Mr. D. A. Oliver, in presenting the Paper, said it might have been noticed that in the preliminary announcement the title had been given as " Machine Research and its Impact on Speeding Production " as distinct from " Machining Research ". It was scarcely necessary to say that there was a big difference between those two words, and, while some people might regret that the title as given in the final programme of the Conference was correct, he would like to make it clear that in his view the finest foundation for future research in machine tools themselves was a wider and deeper knowledge of the conditions of practical machining or of metal removal in general. That point would be brought out by his colleague and co-author, Dr. Fitzgeorge, who would give a summary of the Paper. Mr. Oliver wished to make a few general observations which might be of interest to the Conference before the formal presentation of the Paper. He hoped that in the discussion which was to follow they might receive some stimulating and helpful advice.

It was generally known that the Mechanical Engineering Research Board took a great interest in the advancement of knowledge of the machining process as applied to materials generally, and that work was being undertaken at M.E.R.L., East Kilbride, which might be described as a gigantic offshoot of the original Engineering Division of the National Physical Laboratory. Due to a number of circumstances, the volume of work conducted there had been limited, but the quality had been high, and the work was now gathering momentum.

The Mechanical Engineering Research Board had a Committee devoted to the mechanics of formation and machine shaping of metals. That Committee, of which Mr. Oliver happened to be Chairman, met about four times a year, and at alternate meetings endeavoured to discuss problems relating to machining and machinability. The Committee itself formed a national focal point for work on this subject, without claiming, of course, to be exhaustive. Naturally P.E.R.A. was represented on the Committee, and the universities and large industrial organisations which were interested in this broad subject.

He mentioned that to give the assurance that, however small the scale of the work which was being undertaken, a sense of responsibility to the subject had been shown and had been maintained for seven or eight years, and indeed ever since the Mechanical Engineering Research Board had been formed.

They would all remember the late Dr. Schlesinger who, with Dr. Galloway, at Loughborough College started a school of research on the machining of materials in Great Britain. Before this Professor Wright Baker, of Manchester University, had undertaken cutting tool researches, and these had been reported to a Committtee of the Institution of Mechanical Engineers which Mr. Oliver believed started this work about forty years ago. He thought, however, that the first serious effort could be traced to Schlesinger and Galloway and their early team, who did such excellent sample researches at Loughborough College and later at Melton Mowbray, thereby opening the eyes of production engineers to the type of work which could be done and to the value of the data which became available.

Mr. Oliver was glad to take the opportunity of paying tribute to the help which they had received from Dr. Galloway and his colleagues in the early stages of setting up the B.S.A. Machinability Laboratory round about 1946, which had made it possible to save a year or so of preliminary work. A brief historical survey of machining research in this country was given in the Paper, and he would not elaborate on those aspects.

Turning to the impact of the findings of machining research on machine tool design, he wished to express the following opinions. The modern machine tool incorporated the production experience of many generations of engineers and machinists, rather than

being the direct and logical expression of basic scientific principles. For example, experience had shown that massive slides on the average performed better than those of more slender proportions, and even if slender parts were made which were otherwise suitable, they might have different vibration characteristics and usually lower internal damping. All this had encouraged engineers to be conservative and to welcome only small changes in design, drawing heavily on what had been found empirically to be successful.

A new challenge had now arisen with materials so tough and strong as to be classed as non-machinable according to ordinary standards, while new needs were arising such as servo-controlled and motor-driven parts which must have minimum slide friction, minimum backlash and other fresh features which struck at the very roots of orthodox practice as judged by ordinary standards.

The Authors were primarily concerned with those machine tools such as single-spindle and multi-spindle automatics which were not generally subject to much change, and therefore on some of the newer machine tools for the aircraft industry they spoke more as observers than as actors in the piece. They were, however, concerned very much with the design and performance of small tools and with the machining process generally, and thus were far from indifferent as to what the machine tool of the near future should and must be. Perhaps the advent of automation would give them all a fresh start in this field.

With those preliminary remarks Mr. Oliver proposed to give way to his co-author, Dr. Fitzgeorge, but before doing so he would like to mention that all the Authors were present on the platform and would be available to answer points raised in the discussion in accordance with their experience of the questions raised.

Dr. D. Fitzgeorge then gave a summary of the Paper, and showed slides of some of the machines at the B.S.A. Group Machinability Laboratory. In doing so he gave correct figures for the Adcock and Shipley drilling machine, which differed from those given in the preprint. The main drive, he said, was by a 40-h.p. motor, giving about 460 spindle speeds between 30 and 1,350 r.p.m. It was virtually a continuously-variable machine. A 2-h.p. motor provided the feed, and the value of the feed rate could be chosen from 578 alternatives between 0.8 in. and 65 in. per minute.

Mr. J. Gregson (Development Engineer, The Fairey Aviation Co. Ltd.) said he had three questions to put to the Authors. The first arose from their comments on the machining of high-strength steels which were mostly concerned with milling and turning. He suggested that drilling, reaming and tapping also presented a considerable problem. There was the question of reaming to get finish on holes on high strength steels, and using reamers for more than one hole without regrind. Had any work been done on this? Information had been quoted in regard to these problems on titanium.

His second question was the important one at the present stage of what materials should be used to make machine tools. It had been suggested that spheroidal cast iron might be better than ordinary cast iron, because of the decrease in deflexion due to the higher modulus. A very important point there was the effect of decreasing the damping characteristic. Was any effective work being done to consider the relationship between damping, weight and deflexion for the three materials which were available, namely cast iron, spheroidal graphite cast iron and wrought steel? If it was possible to give way on the superior damping characteristics of cast iron, it might be advisable to turn attention to wrought steel rather than spheroidal graphite cast iron with which it is possible to get a better structure in terms of weight.

The third question was whether the Authors suspected that the fatigue strength of tungsten carbide might have some effect on the life of the carbide under conditions where the rigidity was sufficient to give stress reversals when cutting. Some of the tests which Mr. Gregson's company had carried out on cutting light alloy gave reversals in terms of a million an hour on the tip-edge of the cutter, which was a very high reversal rate. He did not know of any work which had been carried out on the fatigue life of tungsten carbide, and it would be interesting if the Authors had any information on that point.

Mr. Kinman, referring to the drilling, reaming and tapping of high tensile materials, said that their own practical experience was that the drilling presented no problem at all. It was a question of the right design and lubricant and the correct cutting speed. With reaming, if a tungsten carbide reamer was used there was no trouble. Tapping, on the other hand, was extremely difficult. In the high tensile range (85—tons and over), surface treated taps were needed, such as were abtained by nitriding. It was a question of one tap, one hole, and blind holes were almost impossible. It was necessary to have several threads lead or a series of taps, or one would fail completely.

With regard to tool life with tungsten carbide and the question of fatigue, the Authors believed that what had been said was correct. It seemed that under conditions of great rigidity with the minimum of deflexion on the carbide entering and leaving the workpiece, cutting speeds could be greatly increased and tool life would go up enormously. The question of rigidity seemed to be the main point in machining these high tensile materials. With ultra-rigid conditions an entirely different conception was obtained.

Mr. Oliver, referring to Mr. Gregson's question on damping and the use of spheroidal graphite iron in place of cast iron, sail the Authors had had some practical experience of fabricated machine tool bases. They looked very attractive and were easily made when the steel plate could be obtained, but in point of fact they were markedly worse with regard to noise and vibration and had to be stiffened and damped, as compared with the ordinary cast-iron base. The cast-iron base was not unduly porous, but

it did its job well with regard to damping. Their general experience was, however, that there was no need to be worried very much by the different intrinsic damping characteristics of materials, because there was nothing like a very close joint to provide damping of the order of ten times the inherent amount, so that if it was necessary to put damping into a machine tool it would only be necessary to make one very carefully-designed joint and shrink one part on to the other. That joint would then introduce, say, tenfold the damping inherent in the unmodified structure.

Mr. J. Glennie (*Planning Engineer (Weston Factory), Bristol Aircraft Ltd.*) said that production engineers appreciated the importance of the problems involved in using cutting tools with high tensile steels, and apparently the B.S.A. Group were facing those problems in their research work. He would like to know whether the Authors considered it to be important, apart from the design and the manufacture of the cutting tool, to maintain that tool properly from the shop production point of view. Perhaps they might give the Conference the benefit of their experiences in respect of the lapping of such tools, and say whether they preferred metal or Resinoid bonded wheels, particularly in the case of offhand lapping. It would be interesting to know whether they would use a mist coolant or a flow coolant.

Tapping had been dealt with, but he thought rather loosely. Were the manufacturers facing the problem of producing a tap for these materials? They were carrying out research work on milling cutters and so on, but he thought that the tapping problem was greater. Were they doing any research which would enable them to give the production engineer a suitable tap which would satisfactorily produce a tapped hole in high tensile steel, and could such a tap be used in a tapping attachment or must it be used on an orthodox tapping machine?

Mr. Kinman, referring to the grinding of carbide tools, said that many claims were made for the advantages to be obtained from high finishes, but if the finish was reasonable the Authors thought that was sufficient. They considered that a finish of between 3 and 5 micro-inches was satisfactory. Any further finish did not show a profitable return. With regard to the wheels used, it was a question of convenience. For offhand lapping, a metal-bonded wheel was more resistant to misuse, but a Resinoid bonded wheel, if carefully used, would give greater life and faster carbide removal.

With regard to cooling, whether it was done by flow or mist was again a question of convenience. An offhand grinding machine was generally adequately guarded and a copious supply of coolant was no disadvantage, but where that was a disadvantage mist cooling should be used.

With regard to tapping, they were working very hard in trying to develop taps for the high tensile materials, and also for titanium, which presented even more difficulty than high tensile steel; but, as mentioned in the Paper, to some extent designers must co-operate. Tests had shown that a nut tapped to 60% full depth of thread was quite as strong as one tapped to 100%, and that made a tremendous difference in tap life.

Mr. L. J. Bolton (*Production Superintendent (Hydraulics), The Sperry Gyroscope Co. Ltd.*) commented on the fact that the Authors had not mentioned any experiments in the use of liquid carbon dioxide as a coolant, and asked whether they had carried out any experiments on this and come to any conclusions about it.

Mr. Kinman replied that they had not carried out any experiments on carbon dioxide, but they were in close touch with the carbon dioxide suppliers and with other users and would shortly be carrying out experiments. It would appear that carbon dioxide was purely a coolant and not a lubricant, and their tests had shown that in certain conditions one required lubrication and in others one required a coolant. Under conditions where a coolant was necessary lubrication without cooling was ineffective. In such conditions the use of carbon dioxide might be profitable.

Mr. L. G. Burnard (*Chief Development Engineer, Vickers-Armstrongs (Aircraft) Ltd.*) asked whether the capri-honing or vapour-blasting of a ground tool had any effect on its life. Some experiments had been carried out, he said, on the honing of a cutter in this way after it had been ground, and it had been found that this had increased its life considerably.

He had read Mr. Cherry's report on D.T.D. 331, and the rake angles in question, whilst all very well on turning tools, had no real application, at present at any rate, on end mills which must be used for sculpturing the very complicated components in present designs. He would like to know whether the tool manufacturers were going to provide the aircraft industry with end mills with these very high rake angles and, if so, how they would get the strength into the tip, because this was going to make the tip extremely weak. With an inserted tooth cutter it was possible to alter the rake angles considerably, but with an end mill it was necessary to use the rake angle provided by the tool manufacturer.

Mr. Kinman said that the Authors had tried honing and found that it was particularly beneficial on high-speed steels. Unless they were very carefully ground, the surface layer was austenitised. Honing removed that surface layer, with consequent benefit to tool life.

On the question of high rake end mills, there was a weak point there and work would have to be done to see whether cutters could be made with these extremely high rakes. Failing that, it would be necessary to use much lower cutting speeds with conventional cutters. With these cutting speeds, cutting oils were extremely important. Many people did not realise the effect of lubrication on these difficult materials. It was not possible to select a particular oil and say that that was what was going to be used for difficult

materials. All the cutting oils had different active characteristics, and they worked by forming a metallic compound which acted as a lubricant; but the formation of this compound would attack the cutter, and too active an oil would give a short tool life by attacking the cutter and giving an impression of wear. It was necessary to select a cutting oil of the right activity for the particular operation.

Mr. S. W. Potter (*Development Engineer, Royal Aircraft Establishment*) congratulated the B.S.A. Group on doing so much research on the cutting functions of machine tools. This was obviously, he said, one of the major considerations; before it was possible to start on the development of a machine tool, they must be clear in their minds about the functioning of the machine tool and know whether in fact it was going to be a milling principle or a grinding principle, and so on. That was relevant to the design of the machine tool.

The emphasis of the present Conference was rightly on the production of aircraft parts, but there was the related problem of the production of models of aircraft for wind tunnel testing. It was well known that such models had taken far too long in the past to produce, and that had had its repercussions right through the production stage. Here the emphasis was not on *rate* of metal removal from those models, but rather on metal removal with the minimum amount of induced stress in the material left in the model itself.

He was gratified to learn that the B.S.A. Group had removed metal by the fly cutting process, even on 100-ton tensile material. This was an aspect of the subject which was relevant to the job which R.A.E. had to do. They felt that the minimum length of tool-work contact time inherent in single-point machining against, say, a grinding technique would impart a lower stress in the resulting shape, and they were therefore interested in these single-point machining tests. He would like to ask whether any research had been carried out on single-point tool machining in comparison with grinding. It seemed to him that the negative rake of the grinding technique, due to crystal formation, although giving a better surface finish, may, in fact, impart greater stress in the thin aerofoil sections. The surface finish resulting from single-point cutting was still the subject of tests and it seemed to him a major problem to get down to a reasonable surface finish on these models.

In model manufacture they were concerned with shapes which were flexible. They were machining down at trailing edges to a knife edge of say, 0.004 in. thickness, and must balance the upward and downward cutting loads, thereby giving greater rigidity to the workpiece and stability to the resulting model. He had already emphasised that it was necessary to determine the tool geometry before proceeding to the development of special machine tools. There was the ability in Britain to develop these special machine tools when the users knew what they wanted. The R.A.E. were getting to the stage now where they were ready to go ahead with such developments, and had found some support in the machine tool industry.

In reply to Mr. Kinman, Mr. Potter said that the models were made in anything from light alloy to the 100-ton steel which had already been mentioned.

Mr. Kinman, on the question of finish, said that they had found light alloy was not a particularly good material for getting a good finish. The extent to which the single-point cutting tool could be used was limited. It was not possible to take a chip of infinitely small section. For reasonable cutting conditions there was an optimum, and above it and below it there would be a bad cutting condition and therefore a bad finish. He would be inclined to favour grinding with a soft wheel; he thought it would mean less pressure, though he had no actual evidence for that.

Mr. E. B. Loewendahl (*Assistant General Manager, Central Tool & Equipment Co. Ltd.*) said that mention had been made of lubricants for the cutting operations themselves, but there had been no reference to any kind of new lubricating methods for machine tool slides. For example, the use of molybdenum disulphide had recently been introduced by a number of people, and he would like to ask to what extent that improved the stability of slides when tightening closer on the slide gibs, exploiting the improved lubricating possibilities given by materials such as molybdenum disulphide, either in solution or applied in a paste or solid compound. Had the Authors had any experience in that direction, or carried out experiments?

Mr. Kinman said that they had done so and had found that the use of molybdenum disulphide applied to the slideways before lubrication was of considerable benefit, and reduced the co-efficient of friction by 50%, and therefore, stickslip was reduced. They had also obtained better results by using lubricating oils containing active polarised additives which would adhere to the slides by creating an adsorbed layer even if the pressure on the slideways forced the lubricant out. A combination of molybdenum disulphide and a correct lubricant would undoubtedly effect a big improvement.

Mr. W. S. Hollis, B.Sc.(Eng.), A.F.R.Ae.S., (*Assistant Director, Aircraft Production Development Directorate, Ministry of Supply*), raised the question of temperatures at the tool face. He thought it was now fairly well known that machining speeds and the consequent temperature had an effect on tool wear. Work done by Dr. Bowden at Cambridge had shown that there could occur on the tool face formations of intermetallic compounds which were knocked off by the oncoming chip stream. Trigger in the U.S.A. had shown that temperatures on the tool face could reach 1000° - 1100°C. The junction between the chip and the tool face at those temperatures caused a migration of the metallic binder to the chip, thus accelerating cratering of carbide tools. Obviously the B.S.A. Group must have investigated similar work and might be able to comment on it. The Authors had given, it was thought, a temperature of 500°C. without any relation to the higher speeds of cutting.

Mr. Kinman replied that they had given the matter attention in an empirical way, and their findings on the high rake tools tended to confirm the work of other investigators. Failure occurred by mechanical breakdown of the cutting edge due to its fundamental weakness. They also found, in the field of lubrication, that when using a high rake with steel a plain coolant was the most effective and an active cutting oil was of no use. In the mists which they used for cooling they went from a high concentration to plain water and obtained the best results from plain water.

The effect of lubrication was particularly marked in the case of titanium. Their dynamometer readings when drilling titanium with an unsuitable lubricant showed an extremely violent oscillation which indicated a very strong degree of stickslip. Correct lubrication removed that and gave them a smooth curve. There was a high temperature at the interface which could be reduced by using high rake tools or, to go to the other alternative, by using carbide tools where these were suitable, which would stand this high temperature.

Mr. T. S. Lister said that in the case of the very high tensile steels their chemical composition seemed to reduce the tendency to crater on carbide, and that had enabled them to show that the cast-iron grades of carbide seemed to come back into their own. He pointed out that there was no longer, therefore, the disadvantage of the rather poor mechanical properties with titanium. That was an indication ; he would not say that it was established.

Mr. Lister agreed with Mr. Hollis that 500°C. was not a true face temperature ; it was going to be much more than that.

Dr. D. Fitzgeorge said his personal opinion was that the temperature at the actual point of contact of the chip with the tool face was very high, and well above the melting point of the material. That was a pet theory of his. The time of contact was so very brief that the material could exceed the melting point and yet retain its crystalline state. When chip sections were examined, evidence of excessive shearing was seen in the surface layers of the chip which he thought was due to the high temperature. In a thin layer, he believed that the temperature was very high indeed.

Mr. Hollis remarked that he could confirm that also, because from work which he had seen there was a distinct blueing of the chip on the underface compared with its top face, confirming that temperature did not persist as a bulk temperature throughout the chip; in other words, it was a surface temperature relating entirely to the sliding of the chip over the tool.

Dr. Fitzgeorge pointed out that Fig. 11 in the Paper showed the result of a theoretical investigation* into the chip temperature distribution, the information having been given to the Authors by M.E.R.L. That was interesting and showed this temperature gradient.

*Rapier, A. C. " A theoretical investigation of the temperature distribution in the cutting process ". *Brit. Jour. Appl. Phys. 5,* 11, 1954; 400.

Mr. Mark H. Taylor (*Managing Director, Taylor, Taylor & Hobson Ltd.*), commenting on the concluding paragraphs of the Paper, said that there had been some moaning about the machine tool industry. A great deal of useful information had been brought to light in the very instructive Paper which the Authors had presented. They had emphasised how much there was that it was necessary to know about requirements and performance before it was possible to deal with the machine tool problem properly. He imagined that there were many people present who, having heard the Paper, now felt a great deal more confidence in what was being done than they had felt before. He suggested that there was now a case for some group to come together representing the machine tool trades on the one hand and the aircraft industry on the other to get down to the problem and emphasise the most important needs of the industry as a whole.

He thought that there were many problems. For example. the machine tool trade might have a demand for one particular machine, and it was difficult to see the justification in present circumstances for setting a design team to work to meet the requirements of one member of the industry. He thought that there was a case, therefore, for a strong group drawn from both sides to work out what were the most important problems and see whether the machine tool industry could not provide a range of machines which would satisfy a large number of firms in the aircraft industry, and not just one or two. It might well be that, if anything substantial were to be done, some of the prototype machines would have to be nationally supported.

Mr. Oliver said that Mr. Mark Taylor's remarks did not call for a reply, but he thought that they were a most constructive underlining of the conclusion towards which the Authors had been fumbling. The more experience he had in research and development the more he felt that Lord Kelvin's dictum was apposite, namely, if it was possible to specify a problem one was half-way towards its solution.

Mr. J. Cherry (*Senior Lecturer, College of Aeronautics, Cranfield*) congratulated the Authors on their Paper and particularly on emphasising the advantages of basic machinability research. They referred to work on machining 100-ton steel in which they had increased the angle beyond that which he had used in his investigations, from 15° to 40°, increasing the tool life from 36 to 90 minutes. That did not surprise him; it was probably the result which would be obtained when using that reduced feed rate. The feed rate had been reduced to just over .003". His point was that if information was to be useful to production engineers it must be related to cutting conditions, such as depth of cut and rate of feed. The life of the tool would be governed by the heat generated at the tool edge, as had already been pointed out, so that if the cutting conditions and the rate of feed altered, the cutting life would alter.

At Cranfield what they were endeavouring to do was to produce information of a nature which could

be used practically by the aircraft industry. They were carrying out a research programme of machining tough materials—titanium, Nimonics, S.90 and so on —in which they intended to produce data which would give machinability relationships with regard to a range of practical feeds and a range of practical depths of cut, so that planning and production engineers would be able to select the speeds and feeds for the particular tool life which they required, and be able to specify standards of performance in the workshop, which was most important. It meant that prior to the job being done on the shop floor, a reasonable standard could be set as a target for the foremen and the operators. He would, therefore, like to support the Authors in emphasising the advantage of this basic machinability research and in showing how it could eventually be given to production engineers and used for setting shop floor standards.

Mr. G. I. A. Spittle (*Production Manager, The de Havilland Engine Co. Ltd.*), commenting on the reference in the Paper to ways in which metallurgical treatments could improve machinability, said that variations in machinability were obtained in steels which were nominally of the same physical properties and to the same specification. He would like to ask the Authors whether there was scope for improving the consistency of machinability by tighter grain-size control in the manufacture of the steel.

Mr. Lister replied that in his view there was room for something to be done in that direction. Moreover, whilst there was a connection between physical properties and machinability, it had also been shown by some of their recent work that there was an even more important connection between chemical composition and machinability with these high tensile materials which were now of so much interest. For example, the work which they had done on the 3% chromium steel would seem to indicate that at the same tonnage it was very much more difficult to machine than the 4¼% nickel steel in the same condition, and that was probably more important than grain-size. They were going to have to think very hard about the possibility of making greater use of alloying elements in those steels which the aircraft industry found it necessary to machine under these conditions.

Mr. N. Stubbs (*Editor, "Metalworking Production"*), on the question of ceramic tools, said he had been astonished when he went to the Chicago Exhibition to find that firms in America were now developing ceramic cutting tools. A good deal of work had been done on the subject in Britain, but he understood that it had been more or less dropped at the moment. It would be unfortunate if this were to become another example of something being started in this country which the Americans took up and developed. It was also true that the Russians were doing a great deal of work on ceramic tools. Only the other day someone returned from the Prague Fair and after visiting various factories in Czechoslovakia where he found that they were using Russian ceramic tools actually in production. Mr. Stubbs had three of the tips which this visitor had brought back with him. Mr. Oliver might like to comment on the point. It seemed a pity that Britain should drop development work on ceramic tools.

Mr. Oliver said that this was a very important point, and a somewhat delicate one so far as he was concerned. Their laboratory had worked very hard on the ceramic tool problem for a number of years. They could never quite say that they had reached the point where they had overcome all the problems, or that they had one of those foolproof commercial tools which could be sold to everybody without qualification, but they did reach a point where the work was of sufficient promise to justify increased interest.

The original stimulus to develop ceramic tools had been the need for metal economy in view of shortages, at a time when they were wondering whether they would have enough tungsten and what they would do if they had to put tungsten into other alloys. Apart from that, however, the ceramic tool had the tremendous advantage of possessing outstanding wear resistance. In some cases the wear resistance was about four times that of the best tungsten-carbide hard metal. There was the difficulty that, for instance, the chip coming from a high tensile steel (when turning with a ceramic tipped tool) tended to attack the edge of the ceramic tip and cause a certain amount of breaking along the free edge of the tool tip, and sometimes that spread to the cutting edge. If that happened, the tool was finished for the time being. To set against the attractive low cost, there was the problem of fixing it to a shank. They had overcome that after a good deal of hard work. They now found that American practice appeared to favour a clamped tool much more than was the case in this country, and most people were getting successful results by making a fairly massive bar of the ceramic and clamping it, and in that way by-passing some of the earlier problems.

Another interesting point was that there was a tremendous range of new ceramics which could be developed for this purpose. Some of them which had a very smooth, soapy appearance turned out in practice to be superior on light alloys. Some which were well known in this country, the Sintox type, turned out in certain circumstances to show superiority in cutting very abrasive material, and might come back into their own in connection with atomic energy requirements for machining graphite. Graphite was very difficult to machine, especially after it had been refired and recrystallised. When he had first thought of the problem he had imagined that it would be easy, because it would be self-lubricating and everything would slip and slide all over the place, but it turned out to be quite the reverse, and due to internal chemical bonding graphite was one of the most difficult materials to machine, as judged by tool wear. The tool wear in machining graphite was stupendous, and so far the atomic energy piles had been machined by using inserted high-speed steel milling cutters at a very high rate of consumption.

The object of his remarks was not so much to say what the Authors knew about ceramic cutters or had

done on them as to support Mr. Stubbs in his contention that the ceramic cutter was by no means dead. It would undergo further development, and for specialised applications it would come into its own, but there should be no attempt to make it do everything.

Mr. S. G. E. Nash (*Deputy Chief Development Engineer, Bristol Aircraft Ltd.*) supported very strongly what Mr. Mark Taylor had said about the necessity to get together on the question of machining the steels which were to form the structure of the new generation of aeroplanes. There was a need, he suggested, to implicate some more bodies in this matter than the individual aircraft manufacturer and machine tool maker, because it was fair to say that the requirements of the aeroplane would not be the same for low Mach. Number and high Mach. Number planes, or for small research aeroplanes and big bombers. On the other hand, they did not yet know very much about the structural properties of those materials in regard to such characteristics as high elastic modulus and the retention of it with increasing temperature and so on. It would probably be necessary to bring in the steelmakers, because otherwise there would be a great many development problems to solve, which would take up a great deal of time. He thought, too, that the Ministry of Supply had a part to play in formulating the full range of aeroplanes over which these materials were likely to be utilised, because otherwise there would be the danger on which Mr. Mark Taylor touched, namely, of having *ad hoc* solutions to individual problems instead of a general solution to the whole range of problems.

"CONTROL OF PRODUCTION PROCESSES"

Discussion — *concluded from page* 252

The **Chairman,** in closing the session, said that Mr. Smith had brought to their notice some of the various processes with which they had to deal in the manufacture of aircraft. The theme of the Conference was speeding aircraft production. He felt that if the production side took these processes under their wing, and if the development engineers, the planning offices and so on became as interested in them as they were in cutting materials, assembly and all the other problems, they would make a large contribution to the speeding up of production.

There was no doubt that these modern techniques of X-rays, radiographic examination of materials and so on could be a means of saving a great deal of time. There was nothing worse for the production executive than to have a complicated forging or casting 90% machined and then find a flaw in it and have to start all over again. By the use of these processes and of other facilities which were available they could have much more certainty of a production run.

Mr. Smith had also referred to cleanliness, which was certainly the key to the solution of many problems in the factory — surface adhesion, anodising and plating problems and so on. This was most important, and could be secured if the production people would take an interest in it.

Interest in these processes and the full use of them must be initiated from the top and go right down to the floor level, where everyone must realise their importance. It only remained for him to thank Mr. Smith on behalf of the whole Conference for a very instructive and comprehensive Paper.

The Conference then adjourned for half-an-hour.

CONFERENCE SUMMING UP

by The Rt. Hon. Lord SEMPILL, A.F.C., Hon.M.I.Prod.E.,

Past President of the Institution.

LIKE all of us here, I have enjoyed myself very much and benefited greatly from our meetings during these two days. Before I close the meeting I want to thank the Institution for the honour done me in naming the opening Paper at this annual Aircraft Production Conference "The Lord Sempill Paper". Sir Walter Puckey has had to leave the Conference, but I should like to ask him, through Mr. Woodford, the Secretary of the Institution, to express my most grateful thanks to Sir Leonard Lord, the President of the Institution, and to the Council, in terms similar to those which I have used in speaking to you as members of this Conference.

My first job, as was said by Sir Roy Fedden, was when serving my time at the Rolls-Royce works under the chief of the Experimental Department of that day, Mr. Hives. At that time the Company had received an order from the Royal Balloon Corps at Farnborough, the forerunner of the Royal Aircraft Factory, so famous in our aeronautical history, and of the Royal Aircraft Eestablishment, members of which have spoken at this Conference. The Royal Balloon Corps had some historic airships, the Beta, the Gamma and the Delta, which had one or two uncertain functioning motors. That was before the motors of the Fedden generation, which never gave trouble, came into being. One of my first jobs under Mr. Hives was to work on a propeller swivelling gear for the Gamma or the Delta. That was, I am sorry to say, some 47 years ago. I recall with pleasure those old days with that historic company, when Sir Henry Royce and Mr. Rolls were extremely active. It was several years before Mr. Rolls met his death, only a mile or two from here.

After serving my time, I can never be sufficiently grateful to Mr. Hives and everyone on the floor of the shop at Rolls-Royce for all that I learnt from them. We all feel the same, I am sure, about our early days. After that I went into the Flying Corps, and was at one time the last Chief Engineer of the Royal Naval Air Service before it was amalgamated with the R.F.C. into the R.A.F., and then the Chief Engineer of the Royal Air Force ; but all the possibilities of carrying on work in that and other capacities stemmed from what I learnt under Mr. Hives (now Lord Hives) and the others in working with them at Rolls-Royce, and I can never be too grateful for that.

I am sorry that Lord Hives cannot be with us today. He would have come here to make a few opening remarks following Sir Roy Fedden's Paper, but he has had to go on a business tour to New Zealand, Australia and elsewhere. He is a notable figure in the world of aero engine design and development, as well we know. We also think in this connection of the late Sir Henry Royce, the late Major Halford, Bentley, Coatalen, Fedden to mention the leaders, names which come very much to our minds. They undoubtedly held the field in piston engine development until Frank Whittle came along and other lines were taken up.

I can assure you of this. I have attended many Conferences, but I have never studied the Papers with such detailed care as I have given to these. I have made copious notes of the remarks which have been made. Were I to start on what the very charming and efficient Chairman of the Southern Section calls a summing-up, we should certainly be here for a very long time. I am not going to involve you in anything of that kind, because you have to carry out Operation Lunch and Operation Dispersal, and must start fairly soon. I should like, however, to thank Sir Roy Fedden for agreeing to the request that he should give the first Paper which bears my name. I am sure you will agree with me that a better choice could not have been made. Sir Roy is the one man who is entitled to give us views on Britain's aircraft needs. He has a very large measure of independence, backed by tremendous experience in the field of development. It is not many years ago that all the aircraft of the world, both military and commercial, were flying with Fedden motors or with motors directly influenced by his designs.

Future Planning

When I began, at the request of Sir Leonard Lord and the Council, to consider this summing-up, I soon saw that I should be involved in the delivery of a lengthy thesis on all the interesting Papers which have been given. I am not going to do that ; I intend to confine my remarks to the undoubted usefulness and importance of and the future planning for this Conference in the years to come. Before coming to that, however, I want to say a very few

words about the Papers which we have not only enjoyed very much, but from which we have greatly benefited. I have spoken of my gratitude to Sir Roy Fedden, and when the British public come to hear some of the points in his Paper of general interest to themselves, and learn that this historic figure, Sir Roy Fedden, has spoken about the diminutive size of the Air Force, and when they then think of the various happy statements which have been made by official circles from time to time, they will be very much upset when they learn that the inheritors of the greatest Air Force that the world has known, our own, have now an Air Force so small that it numbers some 500 jet fighters and half-a-hundred jet bombers. That will not give the public a very happy feeling, and it may lead to Sir Roy's name being regarded with some disfavour. None the less, he has told us the truth of the situation ; not that all of us here were not aware of that, but sometimes we do not keep these figures in our minds or realise the tremendous implications of the situation in relation to our defence.

The three supporting Papers were of extreme interest. I feel that Mr. Smith, the Chief Inspector of the Aircraft Division of Bristol Aircraft Ltd., gave us a very clear picture of the control of production processes. I only wish that some of the old, historic figures of the A.I.D. had been here to listen to him telling us what could be done with the use of modern technical possibilities.

A Remarkable Team

We have listened this morning to a remarkable Paper on machining research and its impact on speeding production, given by a number of notable figures in that great organisation of the B.S.A., led by the Director of Research. It was a wonderful portrayal of how a number of very experienced people can get together and appear here to be shot at by anyone in the audience, but show themselves able in an admirable way to answer the questions put to them.

The most notable Paper of the three, however, and one which interested me tremendously, was that given by Mr. Gregory and Mr. Vines of the Fairey Aviation Company, on behalf of Sir Richard Fairey. Their concept of integral construction and all that it involves shows how a company with brilliant technical leaders, two of whom we have the privilege of welcoming here, can take up a new line which the aerodynamic forms of to-day demands, and open a development that leads to automation. Their Paper was outstanding. Having induced Sir Roy Fedden to give the opening Paper, he has been followed by a remarkable team, and we have all learnt a great deal from them for which we are extremely grateful.

I should like to say a few words about this Conference and its usefulness. We have always to consider whether we can in any way improve the procedure which we have adopted for these Conferences, of which this is the fourth. What I should like to suggest is that there should be a different method of presentation of Papers. We have seen that with at least one of the Papers there has not been sufficient time to give it the discussion which it required. I should like to put forward for the consideration of the Council that the chief Papers for the next Conference, which I hope will take place here early next year, should be delivered to the Institution at least a month to six weeks before the Conference is due to start, so that all those who come to the Conference will have an opportunity of studying the three of four Papers very thoroughly and of sending in their names to the Institution if they wish to take part in the discussion; and then I suggest that none of the Papers should be read. The written Papers should be circulated beforehand and the Authors should deliver a short prècis of their conclusions, lasting, say, fifteen minutes. This will allow ample time for a full discussion, which could be very much more lengthy than the prècis of the Paper itself. I am sure that that would be an advantage. This Conference is very useful indeed, but it is not fully as useful as it should be when there are those who want to ask questions but who have not time to do so.

I know that you will want me on your behalf to thank, which I do most heartily, the Chairman of the Southern Section, Mr. West, and the Hon. Secretary, Mr. Taylor, and their Committee for all the arrangements which they have made for us here and for getting the co-operation of the University, of the town, and of the technical college of which Mr. West is the principal.

This Institution, as you know, is one of the newer of the remarkable technological Institutions for which our country is famous. It is interesting that this Aircraft Production Conference started as an idea of the Southern Section and has now become a fully accredited national Conference for dealing with this vital question of the technology of aircraft production. We can see that the foundations of our Institution are well and truly laid, since it is possible for a Section of the Institution, in this case the Southern Section, to initiate a Conference which is now held annually and which is the most important Conference in the country on aircraft production.

I should also like on your behalf to thank Mr. Woodford for all the work he has done in assisting the Southern Section, and I thank also the very charming and efficient ladies that he has brought here, who have been so kind and helpful to us all. I should like once again to thank the Institution very much for the honour which has been done me in naming a Paper at this Conference after me, and in giving me an opportunity to say in these few words how grateful I am, and also to express a few ideas for future conferences, which I am sure that our very efficient Secretary, together with Sir Leonard Lord and the Council, will take into account. I thank the Chairman of the Southern Section very much for his kindness to us all and congratulate him and his Hon. Secretary and Committee for all that they have done. You have given us a very jolly time and a wonderful Conference.

The Chairman thanked Lord Sempill very warmly for what he had said and declared the Conference closed.

The Council of the Institution

1955/56

President
Sir Leonard Lord, K.B.E.

Vice-President
E. W. Hancock, M.B.E.

Chairman of Council
G. R. Pryor

Vice-Chairman of Council
H. G. Gregory

Immediate Past Chairman of Council
H. Burke

Past Presidents
Major-General K. C. Appleyard, C.B.E. Sir George Bailey, C.B.E. Sir Alfred Herbert, K.B.E. Norman Rowbotham, C.B.E.
The Rt. Hon. Viscount Nuffield, G.B.E. Sir Walter Puckey J. D. Scaife Dr. H. Schofield, C.B.E.
The Rt. Hon. Lord Sempill, A.F.C. Sir Cecil Weir, K.C.M.G., K.B.E., D.L., M.C.

Presidents of Councils outside the United Kingdom
AUSTRALIAN COUNCIL—J. N. Kirby
SOUTH AFRICAN COUNCIL—H. J. G. Goyns

Chairmen of Regional Committees

East & West Riding
F. T. Nurrish, M.B.E.
Eastern
E. N. Farrar
Midlands
H. Burke
North Midlands
A. S Johnstone
Northern
F. Baker
North Western
F. W. Cranmer
Northern Ireland
G. H. Moore
Scotland
M. C. Timbury
South Eastern
R. E. Leakey
Southern
T. H. Christy
South Western
C. C. Cornford
Wales
W. Abraham

Additional Representatives on Council

East & West Riding
J. E. Hill
Midlands
S. J. Harley
North Western
E. G. Eaton
South Eastern
R. Telford

Chairmen of Standing Committees
K. J. Hume B. H. Dyson R. E. Mills R. Ratcliffe M. Seaman The Rt. Hon. Lord Sempill, A.F.C.
F. Woodifield.

Elected Members
G. R. Blakely R. S. Brown R. M. Buckle R. S. Clark. A. E. Clifford Wm. Core H. H. Dawson
B. H. Dyson. E. P. Edwards. R. Hutcheson B. G L. Jackman A. F. Kelley. R. Kirchner E. Levesley
R. N. Marland Dr. T. U. Matthew H. Spencer Smith H. Tomlinson.

Co-opted Member
T. Fraser, C.B.E.

Chairmen of Sections outside the United Kingdom where Councils are not established

Bombay
R. A. P. Misra
Calcutta
B. F. Goodchild
Canada
C. J. Luby
New Zealand
E. Paton

Overseas Councils

AUSTRALIA

President
J. N. Kirby

Chairman
J. O. Ogden

Vice-Chairman
C. J. Clark

Elected Members
J. W. H. Clarke R. W. Deutsher S. Downie N. Eaton N. Esserman P. E. Frye W. Gwinnett W. L. Hemer
E. J. W. Herbert J. H. Law F. W. Penny C. Pullen J. Steer J. E. Strick H. G. Sutton L. W. Worthington

SOUTH AFRICA

President
H. J. G. Goyns

Vice-President
D. S. Clare

Past Presidents
A. B. Anderson R. H. Arbuckle L. H. L. Badham W. G. Gillespie G. Godfrey J. Henry D. Lion-Cachet
J. Renwick A. C. Wotherspoon

Elected Members
W. E. Bateman G. T. Chawner D. E. Hamm T. H. Hunter C. J. Mogford D. A. Petrie G. M. Pratley
G. G. Tardrew H. H. Waters F. Westall

REGIONAL HONORARY SECRETARIES

East & West Ridings ...	J. L. Townend (Acting)	**Northern Ireland**	W. G. Wyman
Eastern	L. A. Childs	**Scotland**	W. H. Marley
Midlands	B. W. Gould	**South Eastern**	R. Hutcheson
North Midlands	H. Wright	**Southern**	J. W. Taylor
Northern	R. G. Monkhouse	**South Western**	A. Eustace
North Western	J. P. Speakman	**Wales**	J. Bolwell

Secretary of the Institution
W. F. S. Woodford

SECTION CHAIRMEN

C. J. Clark	*Adelaide*	F. Baker	*North Eastern*
T. W. Elkington	*Birmingham*	G. H. Moore	*Northern Ireland*
R. A. P. Misra	*Bombay*	V. Crowther	*Norwich*
B. F. Goodchild	*Calcutta*	L. Shenton	*Nottingham*
C. J. Luby	*Canada*	J. W. G. Pringle	*Oxford*
H. M. Sawyer	*Cornwall*	H. F. Adams	*Peterborough*
W. G. Rootes	*Coventry*	E. G. Eaton	*Preston*
A. Short	*Derby*	T. H. Christy	*Reading*
G. R. Whitehead	*Doncaster*	W. T. Cottingham	*Rochester*
A. Williamson	*Dundee*	E. Levesley	*Sheffield*
F. T. Dyer	*Eastern Counties*	B. G. Williams	*Shrewsbury*
A. Betts Brown	*Edinburgh*	W. G. Gillespie	*South Africa*
M. C. Timbury	*Glasgow*	R. Telford	*South Essex*
T. E. Love	*Gloucester*	W. Abraham	*South Wales*
F. J. Everest	*Halifax*	F. T. West	*Southern*
J. C. Routledge	*Leicester*	H. Porter	*Stoke-on-Trent*
R. S. Hind	*Lincoln*	J. O. Ogden	*Sydney*
J. H. Winskill	*Liverpool*	R. H. Archer	*Tees-Side*
R. E. Leakey	*London*	W. H. Bowman	*West Wales*
R. M. Buckle	*Luton*	C. C. Cornford	*Western*
T. A. Stoddart	*Manchester*	C. L. Old	*Wolverhampton*
C. P. Pullen	*Melbourne*	R. H. Higgs	*Worcester*
E. Paton	*New Zealand*	D. H. Turnbull	*Yorkshire*

GRADUATE SECTION CHAIRMEN

A. C. Turner	*Birmingham Graduate*	J. P. Speakman	*Manchester Graduate*
E. N. Coates	*Coventry Graduate*	T. Lewins	*North Eastern Graduate*
M. Alderdice	*Halifax Graduate*	E. Willcox	*Sheffield Graduate*
D. Portman	*Liverpool Graduate*	R. Powell	*Western Graduate*
F. H. Johns	*London Graduate*	E. Springthorpe	*Wolverhampton Graduate*
R. St. John Aylieff	*Luton Graduate*		

SECTION HONORARY SECRETARIES

AUSTRALIA

Adelaide (South Australia) ...	W. L. Hemer, 6 Bedford Street, Brooklyn Park, South Australia.
Melbourne (Victoria, Australia)	R. W. Deutsher, Bank House, 11 Bank Place, Melbourne, C.I., Australia.
Sydney (New South Wales) ...	A. Welsh, Room 802, 16 Barrack Street, Sydney, Australia.

CANADA

Canada	P. M. Wood, 7 Tottenham Road, Don Mills, Ontario, Canada.

INDIA

Bombay	E. Fernandes, c/o Burmah Shell, Royal Insurance Bldg., Jamshedi Tata Road, Churchgate, Bombay.
Calcutta	C. K. Haldar, Calcutta Technical School, 110 Surenda Nath Banerjee Road, Calcutta, 13.

NEW ZEALAND

New Zealand	G. Stedman, 3 Harrison Avenue, Belmont, Takapuna, Auckland, N.2, New Zealand.

SOUTH AFRICA

South Africa	The Secretaries, Institution of Production Engineers, Barclays Bank Buildings, Corner Commissioner and Harrison Streets, Johannesburg.

UNITED KINGDOM

Birmingham	B. W. Gould, Dept. of Industrial Administration, College of Technology, Gosta Green, Birmingham, 4.
Cornwall	F. G. Hawke, 17 Church Road, Pool, Redruth, Cornwall.
Coventry (Acting)	A. S. Hopkins, 39 Oaks Road, Kenilworth, Warwickshire.
Derby	P. Warburton, 16 Vicarage Road, Chellaston, Derby.
Doncaster	W. H. Edwards-Smith, "Hindscarth", Melton Road, Sprotborough, Nr. Doncaster.
Dundee	J. Nicolson Low, Technical College, Bell Street, Angus, Scotland.
Eastern Counties	A. B. Brook, Davey, Paxman & Co. Ltd., Britannia Works, Colchester.
Edinburgh	W. Sinclair, Brown Bros. & Co. Ltd., Rosebank Ironworks, Edinburgh, 7.
Glasgow	W. H. Marley, G. & J. Weir Ltd., Cathcart, Glasgow, S.4.
Gloucester & District ...	C. L. Mawhood, 132 Brooklyn Gardens, Cheltenham.
Halifax	F. J. Everest, David Brown Industries Ltd., Park Gear Works, Huddersfield.
Leicester & District	D. G. Swinfield, 65 St. Saviour's Road, Leicester.
Lincoln	H. Wright, 101 Longdales Road, Lincoln.
Liverpool	R. T. Spencer, 44 Kremlin Drive, Stoneycroft, Liverpool 13.
London	R. J. C. Whitaker, The Glacier Metal Co. Ltd., Ealing Road, Alperton, Middlesex.
Luton	J. F. W. Galyer, Engineering Dept., Luton & South Beds. College of Further Education, Park Square, Luton, Beds.
Manchester	J. P. Speakman, 223 Douglas Road, Atherton, Nr. Manchester.
North Eastern	A. C. Foskew, 35 Oakwood Avenue, Low Fell, Gateshead, 9.
Northern Ireland	W. G. Wyman, 'Hopecroft', Glenavy, Co. Antrim.
Norwich	L. A. Tillett, 21 St. Martins Road, Norwich, Norfolk.
Nottingham	C. N. T. Manfull, Chellaston House, Thurgarton Street, Nottingham.
Oxford	E. A. Wootton, 8 Manor Road, Grimsbury, Banbury, Oxon.
Peterborough	N. Holmes, "Arncliffe" 11 Mary Armyn Road, Orton Longuevinne, Peterborough, Northants.
Preston	R. Thompson, 71 Willows Lane, Accrington, Lancs.
Reading	R. W. H. Mark, 'The Beeches', 41 Reading Road, Woodley, Berks.
Rochester & District	W. G. Clements, 11 Charing Road, Gillingham, Kent.
Sheffield	T. F. Newton, 20 Exley Avenue, Sheffield, 6.
Shrewsbury	W. M. Buchan, Llanberis, 36 Mytton Oak Road, Shrewsbury.
Southern	J. W. Taylor, 44 Deacon Road, Bitterne, Southampton.
South Essex	D. S. Redhead, Marconi's Wireless Telegraph Co. Ltd., Chelmsford, Essex.
South Wales & Mon. ...	J. Bolwell, Creed & Co. Ltd., Treforest Industrial Estate, Pontypridd, Glam.
Stoke-on-Trent	W. R. Bailey, "Rivelyn", Crossfield Avenue, Knyperfley, Biddulph, Stoke-on-Trent.
Tees-Side	T. A. Horsley, 24 Clarence Road, Nunthorpe, Nr. Middlesbrough.
Western	A. Eustace, 19 Ferndale Road, Northville, Bristol, 7.
West Wales	H. P. Sanderson, I.C.I. Ltd., Metals Division, Waunarlwydd, Nr. Swansea.
Wolverhampton	R. J. Sury, Widdicombe House, 2 Buttons Farm Road, Penn, Wolverhampton.
Worcester	R. Wheeler, Old Farm House, Parish Hill, Bournheath, Nr. Bromsgrove, Worcester.
Yorkshire	J. L. Townend, 26 Moor Allerton Drive, Street Lane, Leeds, 17.

CORRESPONDING MEMBER IN MIDDLE EAST

J. Merkine, 45 Arlozoroff Street, Ramat-Gan, Israel.

CORRESPONDING MEMBER IN EGYPT

A. F. Abdo, 29 Abo Taleb Street, Terha Bolackia, Shouba, Cairo.

CORRESPONDING MEMBER IN IRAQ

W. G. Rooke, Production Engineer, Iraqi State Railways, Shalchiyah, Baghdad, Iraq.

CORRESPONDING MEMBER IN BRITISH WEST AFRICA

H. P. Halfter, Gold Coast Rlys. & Harbour Admin., P.O. Box 202, Takoradi, Gold Coast, B.W.A.

GRADUATE SECTION HONORARY SECRETARIES

Birmingham	W. E. Hipkiss, 17 Briery Road, Halesowen, Birmingham.
Coventry	D. W. Wright, 14 Haynestone Road, Coundon, Coventry.
Halifax	C. W. Overin, 353 Whitehall Road, Westfield, Wyke, Nr. Bradford, Yorks.
Liverpool	G. L. Smith, 17 Withers Street, Liverpool, 7.
London	R. J. Temple, 59 Brooke Road, Stoke Newington, London, N.16.
Luton	M. J. Hemmett, 20 King Georges Avenue, Watford, Herts.
Manchester	R. C. Yarnell, 1 Demesne Road, Whalley Range, Manchester, 16.
North Eastern	R. Scott, 71 Monk Street, Gateshead, 8, Co. Durham.
Sheffield	G. Shaw, 151 Westwick Crescent, Sheffield, 8.
Western	T. G. Mossman, Y.M.C.A. Hostel, Colston Street, Bristol, 1.
Wolverhampton	W. L. Pace, "Linden" 10 Ezekiel Lane, Short Heath, Willenhall, Staffordshire.
Yorkshire	(Acting) J. L. Townend, 26 Moor Allerton Drive, Street Lane, Leeds 17.

LOUGHBOROUGH COLLEGE STUDENT SECTION

Chairman: A. K. Windeler

Secretary: S. K. Maini, Hazlerigg Hall, Loughborough, Leics.

Old Time Standards

THE OXGANG

The oxgang, a medieval land measure, was equivalent to 13 Scots acres. The name derived from the fact that this was approximately the area that could be ploughed in a day, using one ox.

Nowadays standards must be authoritative and dependable and are, therefore, derived from the most expert opinion available. In some cases the existing procedure of a producer is accepted as the best practice of the art and is taken as a basis for the standard in question.

Thus British Standard 1004 (Zinc Alloys for Die Casting) was based on the established practice of the Imperial Smelting Corporation in the production of MAZAK.

MAZAK

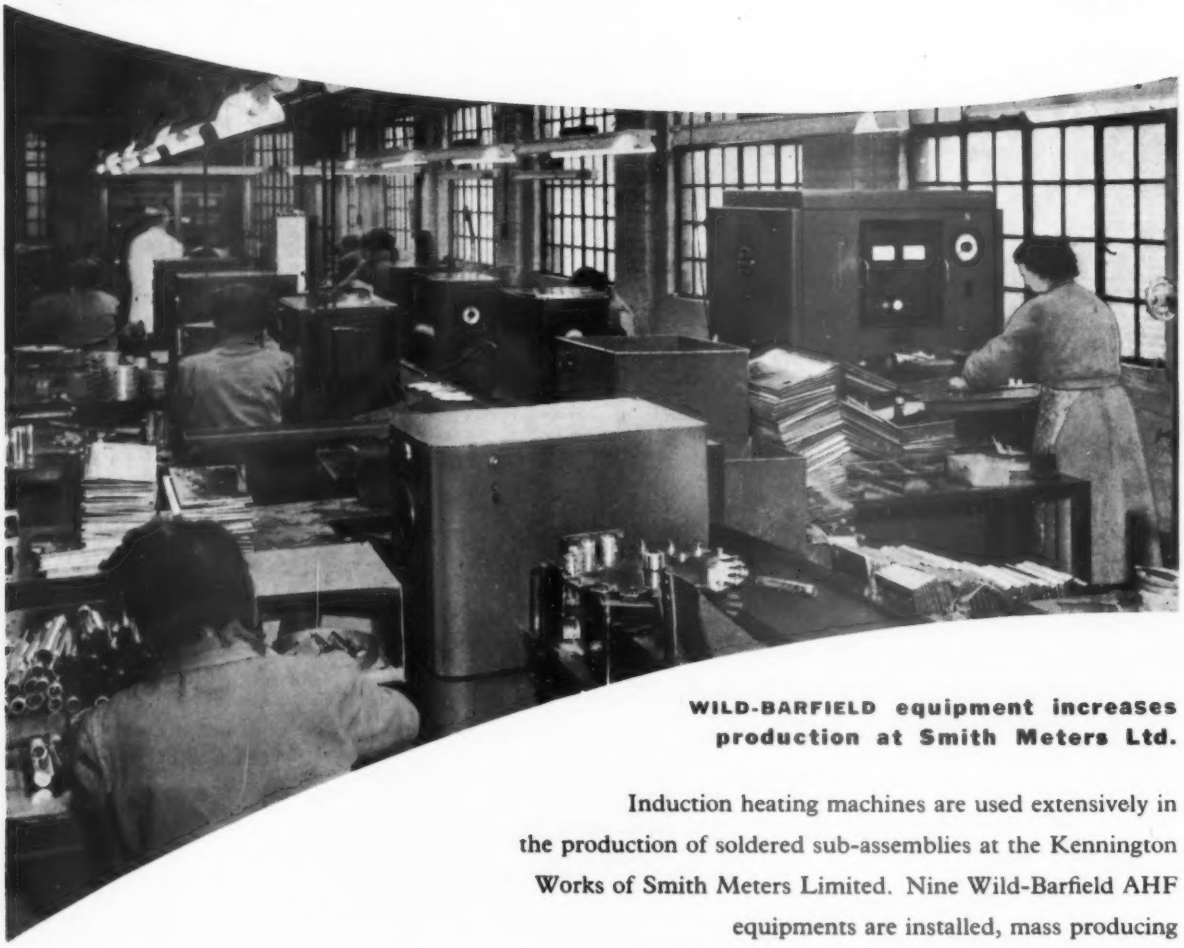
Foremost by all Modern Standards

IMPERIAL SMELTING

U.K. MEMBER OF THE CONSOLIDATED ZINC CORPORATION LIMITED

IMPERIAL SMELTING CORPORATION (SALES) LIMITED, 37 DOVER STREET, LONDON, W.1

saving all along the line . . .



WILD-BARFIELD equipment increases production at Smith Meters Ltd.

Induction heating machines are used extensively in the production of soldered sub-assemblies at the Kennington Works of Smith Meters Limited. Nine Wild-Barfield AHF equipments are installed, mass producing assemblies for Smith Gas meters. This is just one example of how Wild-Barfield machines speed production.

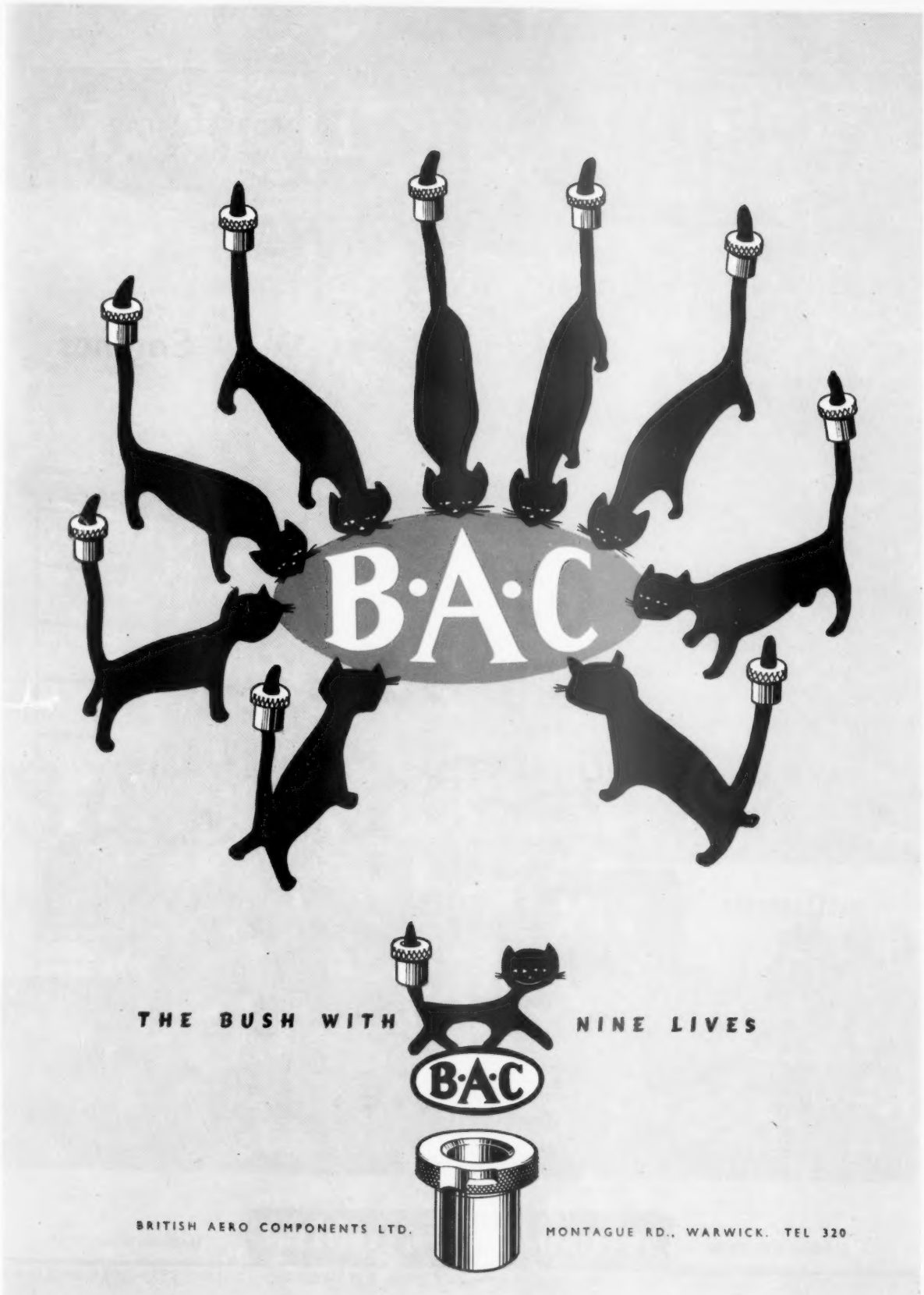
WILD BARFIELD AHF

INDUCTION HEATING SPEEDS PRODUCTION

WILD-BARFIELD ELECTRIC FURNACES LIMITED *(Induction Heating Division)*

50 OXGATE LANE, CRICKLEWOOD, LONDON, N.W.2. Telephone: GLAdstone 8030

WB 36


B·A·C
THE BUSH WITH
NINE LIVES
B·A·C
BRITISH AERO COMPONENTS LTD.
MONTAGUE RD., WARWICK. TEL 320

ASQUITH **HRG** HORIZONTAL BORER

installed for boring and facing the crankcases of high quality Diesel Engines

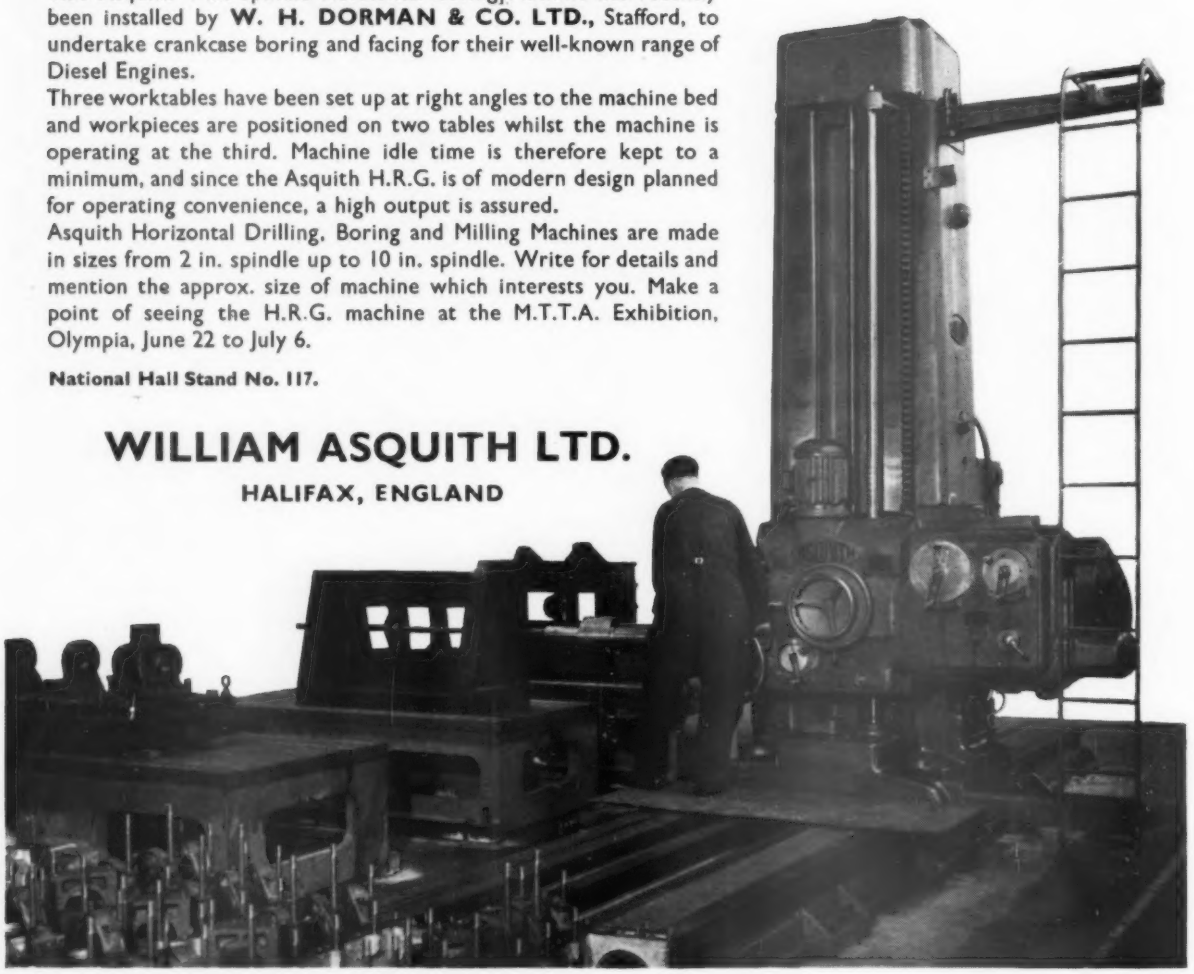
This Asquith 4 in. Spindle Horizontal Boring Machine has recently been installed by **W. H. DORMAN & CO. LTD.,** Stafford, to undertake crankcase boring and facing for their well-known range of Diesel Engines.

Three worktables have been set up at right angles to the machine bed and workpieces are positioned on two tables whilst the machine is operating at the third. Machine idle time is therefore kept to a minimum, and since the Asquith H.R.G. is of modern design planned for operating convenience, a high output is assured.

Asquith Horizontal Drilling, Boring and Milling Machines are made in sizes from 2 in. spindle up to 10 in. spindle. Write for details and mention the approx. size of machine which interests you. Make a point of seeing the H.R.G. machine at the M.T.T.A. Exhibition, Olympia, June 22 to July 6.

National Hall Stand No. 117.

WILLIAM ASQUITH LTD.
HALIFAX, ENGLAND



Sales & Service for . . . **DRUMMOND-ASQUITH** *. . . the British Isles*

DRUMMOND-ASQUITH (SALES) LTD., KING EDWARD HOUSE, NEW ST., BIRMINGHAM

'Phone: Midland 3431 (7 Lines) *Also at LONDON: 'Phone: Trafalgar 7224 (3 lines) and GLASGOW: 'Phone Central 3411*

A.129

MAXICUT

3A

for High Quality, Heavy Duty Gear Shaping

The illustration shows the Maxicut 3A Gear Shaper cutting dual camshaft gears for high quality, individually built diesel engines. The versatility, ease of setting and high accuracy are qualities of this machine that have proved ideal for this type of production. It is, of course, equally applicable to long-run mass production work. The No. 3A Maxicut Gear Shaper cuts spur and helical gears up to 18 in. pitch dia. by ¾ diametral pitch. Write today for a catalogue and get full details. Make a point of seeing this machine at the M.T.T.A. Exhibition, National Hall, Stand No. 413.

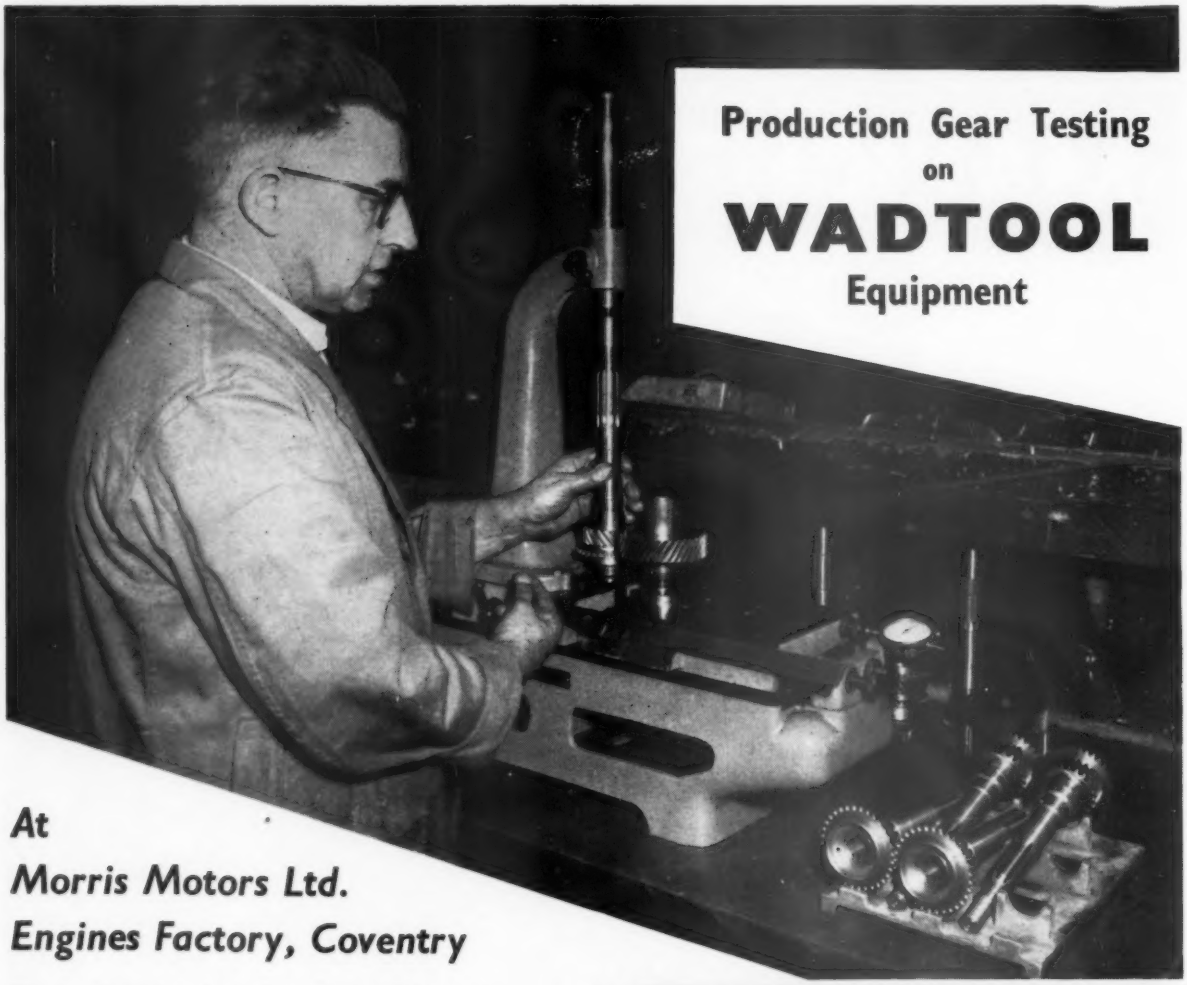
DRUMMOND BROS. LTD., GUILDFORD, ENGLAND

Sales and Service for . . . **DRUMMOND-ASQUITH** *. . the British Isles*

DRUMMOND-ASQUITH (SALES) LTD., KING EDWARD HOUSE, NEW STREET, BIRMINGHAM

'Phone: Midland 3431 (7 lines) *Also at LONDON, 'Phone: Trafalgar 7224 (3 lines) and GLASGOW, 'Phone: Central 3411*

D126



Production Gear Testing on WADTOOL Equipment

At Morris Motors Ltd. Engines Factory, Coventry

The top illustration shows the equipment being used with the centre attachment fitted, for checking drive gears for B.M.C. 'C' type engines.

The lower photograph shows the machine set up for testing lay gears for the same engine.

The Wadtool Gear Tester provides a quick, accurate and economic method of checking production gears — that's why it is used by mass production organizations like motor manufacturers.

Two saddles mounted on guide ways carry the gears to be checked. One saddle is clamped in position and the other 'floats' on steel balls and is kept in contact by spring pressure. Movement of this saddle caused by irregularities in the gears is recorded on a dial indicator. Attachments are available for accommodating various types of gears. Max. capacity is 10" dia.

Write today for full details and make a point of seeing it at the M.T.T.A. Exhibition, National Hall Gallery, Stand No. 413.

Sales & Service for . . . **DRUMMOND-ASQUITH** . . . the British Isles

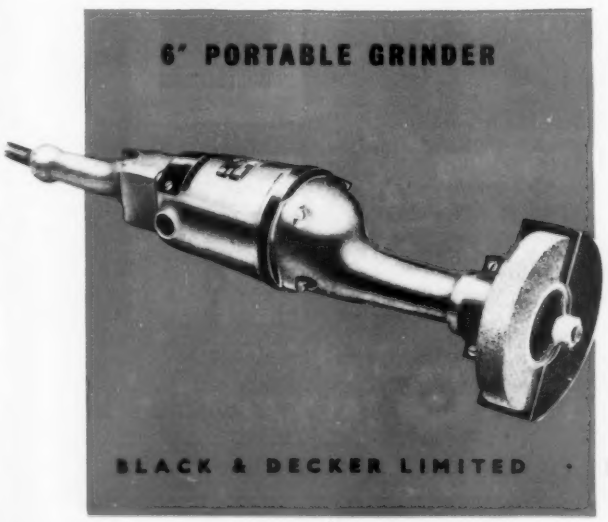
DRUMMOND-ASQUITH (SALES) LTD., KING EDWARD HOUSE, NEW ST., BIRMINGHAM

'Phone: Midland 3431 (7 lines) Also at LONDON: 'Phone Trafalgar 7224 (3 lines) and GLASGOW: 'Phone Central 3411

HF102

Introducing two powerful ABRASIVE TOOLS

The new Black & Decker 7" Sander-Grinder and the redesigned 6" Portable Grinder now give more power than ever before. The 7" Sander-Grinder is lighter, 90% more powerful than previous models and has the abundant power necessary for continuous heavy duty production work. You can choose one of three spindle speeds to do the kind of work you want. The tool can be adapted for use with sanding discs, saucer grinding wheels, wire cup brushes or planer heads. The higher speed models are specially designed for use with the depressed centre 'cut off' wheel which obsoletes the grinding wheel for many types of grinding job.



Redesigned to give 85% more power, the latest, lighter 6" Portable Grinder is ideal for sustained grinding, buffing and wire brushing jobs.

These two new powerful tools give greater output— faster than ever before. Write for leaflets giving full details.

Black & Decker

PORTABLE ELECTRIC TOOLS

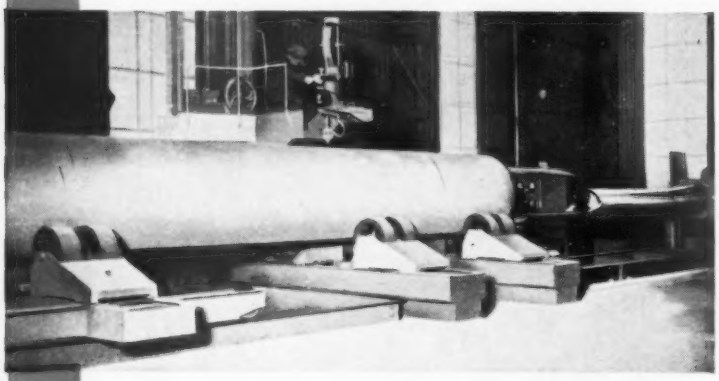
Smee's

When it comes to WELDING

Automatic Welding?

We sell the whole works

As the biggest and most experienced people in automatic arc welding, Quasi-Arc Limited offer the Production Engineer advantages he can get nowhere else. They are ready to supply him promptly with *everything he needs*—plant, welding materials, expert service—all from one old-established and reliable firm.



External and internal welding of Class 1 boiler drums, by the Fusarc process. Note the versatile cantilever—supported automatic welding head; boom-type internal welder (right) with effective welding traverse of 15′ 0″; and the adjustable motorised roller bed, working in conjunction with an idler-bed unit. All manufactured, installed and serviced by Quasi-Arc Limited—and only one of many complex automatic welding installations now in production.

Continuous Welding Processes

Quasi-Arc are the only people who make and sell *two* continuous automatic arc welding processes—Fusarc and Unionmelt, with all their present-day variations.

Fusarc

The biggest-selling continuous covered electrode process in the world—and in its field the most economical. Fusarc with its visible arc, runs fast and efficiently, and gives excellent results both indoors and outdoors.

Unionmelt

The world-renowned submerged arc process, giving X-ray sound welds with perfect finish. There is no spatter and no flash. It is rapidly expanding into light plate welding as well as in heavy fabrication work.

Welding Manipulators

Quasi-Arc supply a wide variety of manipulative equipment from manipulators and positioners to roller bed units. They are built on years of experience and development and can be incorporated with any welding process in complete automatic welding installations.

The interests and activities of The Quasi-Arc Company Limited and Fusarc Limited in the well-known processes

Quasi-Arc · Fusarc · Unionmelt · Sigma · Heliarc · Twin-Arc

have been combined in order to provide a thoroughly comprehensive and effective service to the welding industry.
The headquarters of the new organisation—named Quasi-Arc Limited—are at Bilston, Staffordshire, with works at Bilston and Gateshead.

Come to QUASI-ARC

QUASI-ARC LIMITED · BILSTON · STAFFORDSHIRE

Qualities for economy

Somewhere in the grades of these quality bronze alloys you will find the properties required for that component you have in mind. Bringing greater economy, too, CROTORITE, PARSONS and IMMADIUM bronzes are supplied in extruded rolled and forged rods, bars, tubes etc., and specially shaped forgings which can save you a great deal in machining costs.

PARSONS
MANGANESE BRONZE

CROTORITE
ALUMINIUM BRONZE

IMMADIUM
HIGH TENSILE BRONZE

Technical data and advice are available on request

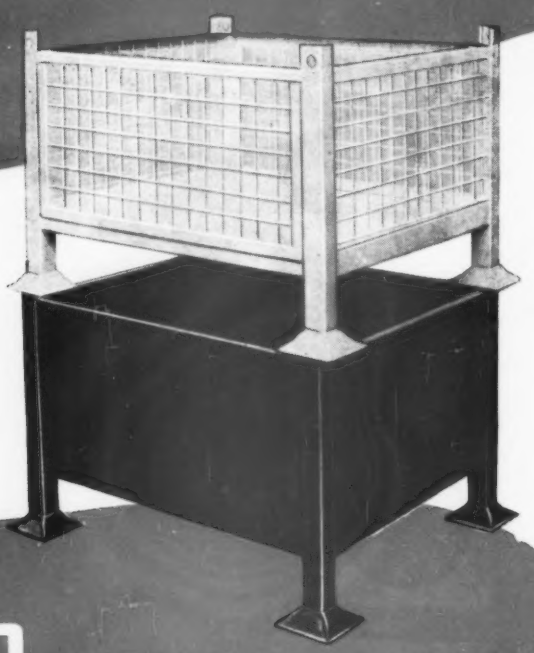
THE MANGANESE BRONZE & BRASS COMPANY LIMITED

HANDFORD WORKS HADLEIGH RD. IPSWICH · TELEGRAMS BRONZE IPSWICH · TELEPHONE IPSWICH 2127

VICTROLEC

HEAVY-DUTY BOX PALLETS

Safety Stacking

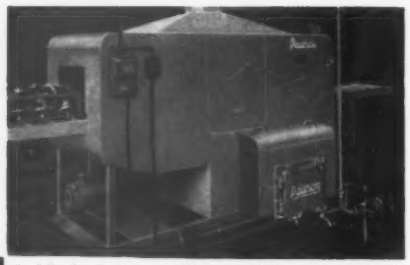


VICTROLEC LTD VICTORIA ROAD · ASTON BIRMINGHAM, 6

Telephone: East 1454 (3 lines)
Telegrams: 'Halvic' Birmingham

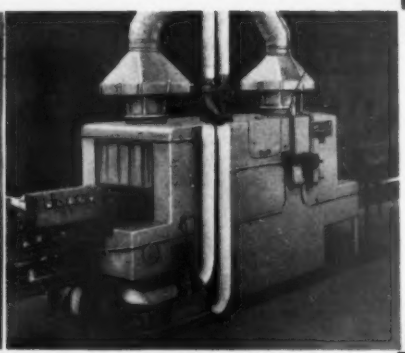
The most practical plant for Cleaning METAL PARTS

PRIOR TO ASSEMBLY, and BEFORE and AFTER REPAIRS



A 'Junior' type machine supplied to a Midlands Motor Car Works.

Supplied for the washing and drying of Tractor parts. Crank Shafts, Sumps, Pressings, etc.

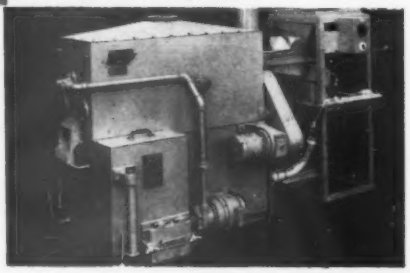


A model 'A' machine, washing parts of motor car engines prior to assembly.

Dawson

DE-GREASING MACHINES

A Rotary Drum machine for removing swarf and grease from small components.



Dawson Metal Parts cleaning machines are supplied for all branches of the engineering industry. Their chief characteristics are robustness of design, small number of working parts and simplicity of operation. Space only permits the illustration of four of the many types of machines built for quick economical washing and drying of Metal Parts.

Sole Distributors

DRUMMOND-ASQUITH (Sales) LTD., King Edward House, New St., Birmingham

Telephone—Midland 3431

Manufacturers—DAWSON BROS. LTD., Gomersal, LEEDS *Tel.—Cleckheaton 1080 (5 lines)*

London Works—406 Roding Lane South, Woodford Green, Essex. *Tel.—Wanstead 7777 (4 lines)*

THE TORCH OF INDUSTRY
NEW! the BEAGLE
A transportable profiler that cuts constant angle bevels automatically on curves of any radii
You can carry the Beagle — all up weight 125 lb. — to the job and set it up to cut in a few minutes. Electrically driven and guided by a hand steered tracing wheel, it will cut any profile in steel up to 2" thick, operating direct from working drawings with the greatest accuracy. No waiting for the work to come to the machine — no expensive templates needed. And the Beagle is fitted with a unique cutter which will maintain any bevel up to 45° round any profile.
BRITISH OXYGEN
British Oxygen Gases Ltd., Industrial Division, Bridgewater House, St. James's, London, S.W.1.

If you know the best when you see it...

sooner or later you buy Eclipse TOOLS

HACK SAW BLADES · TOOL BITS
PERMANENT MAGNET CHUCKS
MAGNETIC TOOLS & ENGINEERS' HAND & PRECISION TOOLS

Made by James Neill & Co. (Sheffield) Ltd. and obtainable from all tool distributors

UX2

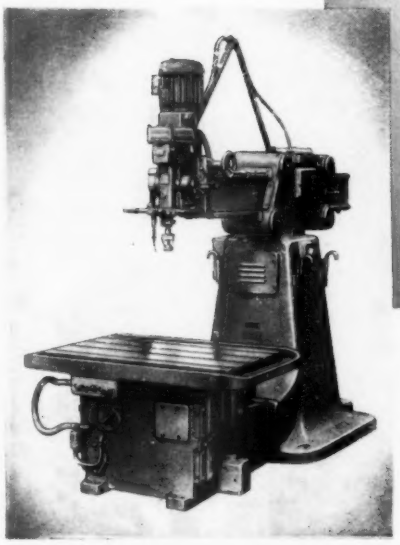
BSA Huller

British Built

Automatic TAPPING & THREADING MACHINES

Fast and easy to operate, these machines meet the most stringent demands of modern mass production. Their outstanding features include entirely automatic tapping or threading operations, a wide range of speeds, and precise limitation of feed depths; the spindle is fed and returned at the exact pitch. The range includes bench, column and a radial type. Capacities from 3/16" to 1.3/16" (4.75 to 30.16 mm) thread diameter, in steel.

Please ask for catalogue



B.S.A. TOOLS LTD • BIRMINGHAM • ENGLAND

Sole Agents Great Britain

BURTON GRIFFITHS & CO., LTD • KITTS GREEN • BIRMINGHAM 33

Telephone: STECHFORD 3071

Cincinnati

NEW

HyPowermatic

PRODUCTION MILLING MACHINES

PLAIN AND DUPLEX

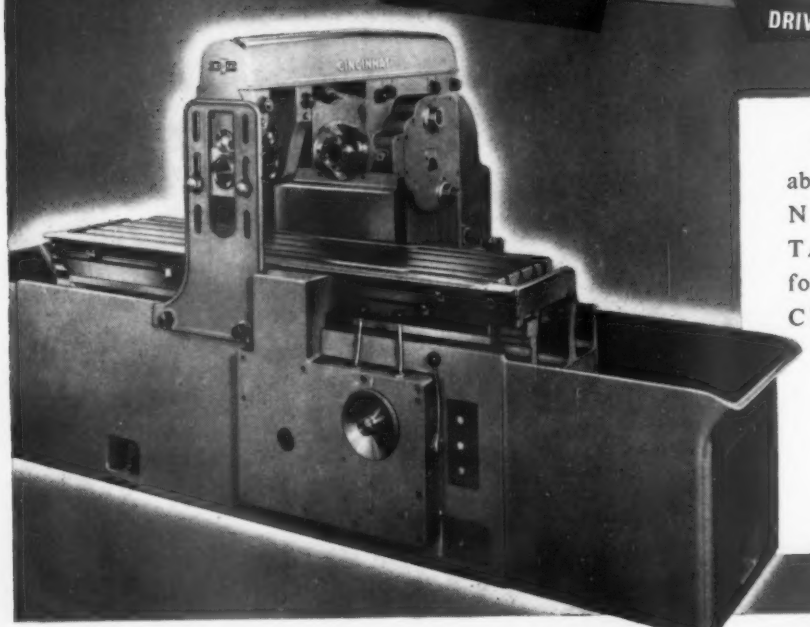
42 SIZES OF EACH

AUTOMATIC TABLE CYCLES

CLIMB MILLING

UP TO 50 H.P. SPINDLE DRIVE

36" to 168" TABLE TRAVERSE



You will wish to learn more about this machine with its NEW HYDRAMECH TABLE DRIVE designed for both conventional and CLIMB MILLING.

Write today for Catalogue No. M-1871-E to CHARLES CHURCHILL & CO. LTD., London, Birmingham, Manchester, Newcastle-on-Tyne or Glasgow

CINCINNATI MILLING MACHINES LTD . BIRMINGHAM 24

KG
MACHINE TOOLS

Safeguarding for the future their traditional engineering craftsmanship, **Rolls Royce Ltd.,** employ The Keighley 'KN' Internal Grinder for the training of their apprentices. For internal, external and face grinding to the highest degree of accuracy, the multi-purpose 'KN' is one of a range of fine quality machine tools manufactured by Keighley Grinders (M.T.) Ltd.

ROLLS ROYCE

PHOTOGRAPH BY COURTESY OF ROLLS ROYCE LTD.

ONE OF THE NEWALL GROUP

Please address enquiries to:

NEWALL GROUP SALES LTD

PETERBOROUGH Phone: PETERBOROUGH 3277-8-9 KEIGHLEY Phone: KEIGHLEY 4294

Avro VULCAN (Photograph by courtesy of A. V. Roe & Co. Ltd.)

Churchill

By their ability to maintain low limits and fast production rates, CHURCHILL Precision Grinders make an important contribution to the outstanding achievements of the British Aircraft Industry.

★ **The CHURCHILL Model 'VXA' 60" x 16½" Vertical Spindle Surface Grinding Machine**

THE CHURCHILL MACHINE TOOL CO., LTD., BROADHEATH, Nr. MANCHESTER

Export Sales Organisation : Associated British Machine Tool Makers Limited, London, Branches and Agents

Home Selling Agents : Charles Churchill & Co., Ltd., Birmingham and Branches

International Machine Tool Exhibition, London, 1956, June 22 to July 6 — Stand 59 Grand Hall, Olympia.

PRECISION *plus* PRODUCTION

C625C

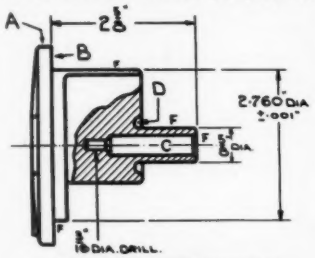
For Maximum Production

Ward No. 2A CAPSTAN LATHE

FITTED WITH 6½" 'PRATT' AIR-OPERATED 3-JAW CHUCK

PUMP BODY

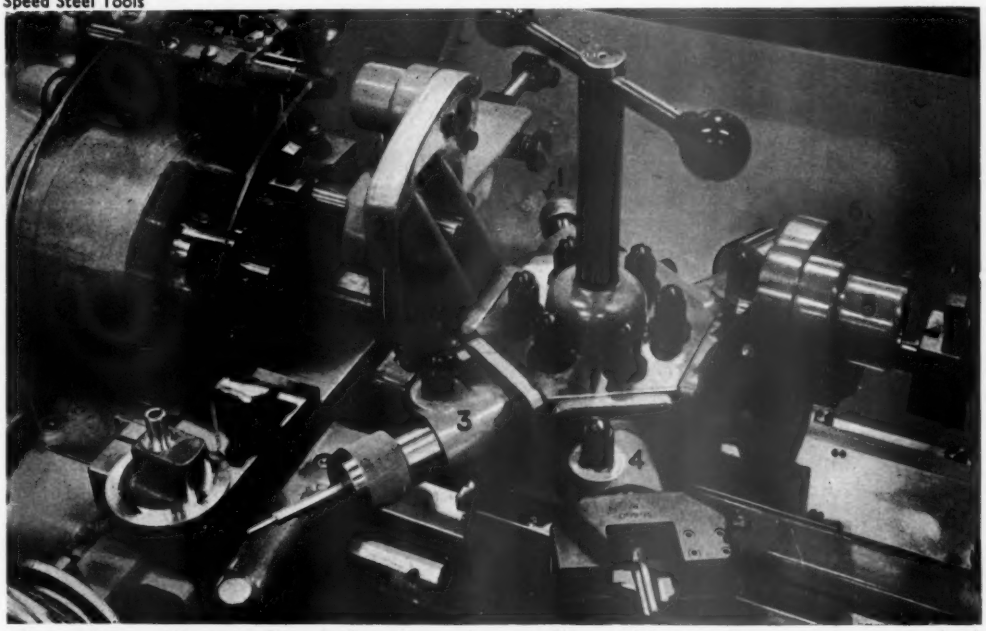
Floor to Floor Time: 50 seconds.



BRASS STAMPING

Tungsten Carbide and High Speed Steel Tools

DESCRIPTION OF OPERATION	Tool Position		Spindle Speed R.P.M.	Surface Speed Ft. per Min.	Feed Cuts per inch
	Hex. Turret	Cross-slide			
Chuck externally at A	—	—	—	—	—
Face Flange B	—	Rear	2041	2000	Hand
Start Drill C	1	—	2041	200	Hand
Drill and Knee Turn 2·760" dia.	2	—	2041	1475	120
Drill ⅛" dia.	3	—	2041	100	Hand
Bore C, Turn ⅝" dia. and recess D and Face End	4	—	2041	535	120
Finish Knee Turn 2·760" dia.	5	—	2041	1475	120
Ream C	6	—	321	30	Hand
Remove	—	—	—	—	—



Capacity: 1⅜ in. dia. hole through spindle. 11¼ in. dia. swing over bed.
Spindle: Mounted in ball and roller bearings.
Powerful friction clutches running in oil transmit power through ground gears.

OUR COMPLETE RANGE INCLUDES CAPSTAN AND TURRET LATHES WITH CAPACITIES UP TO 35 in. SWING OVER BED AND 8½ in. DIA. HOLE THROUGH SPINDLE.

Full details on request

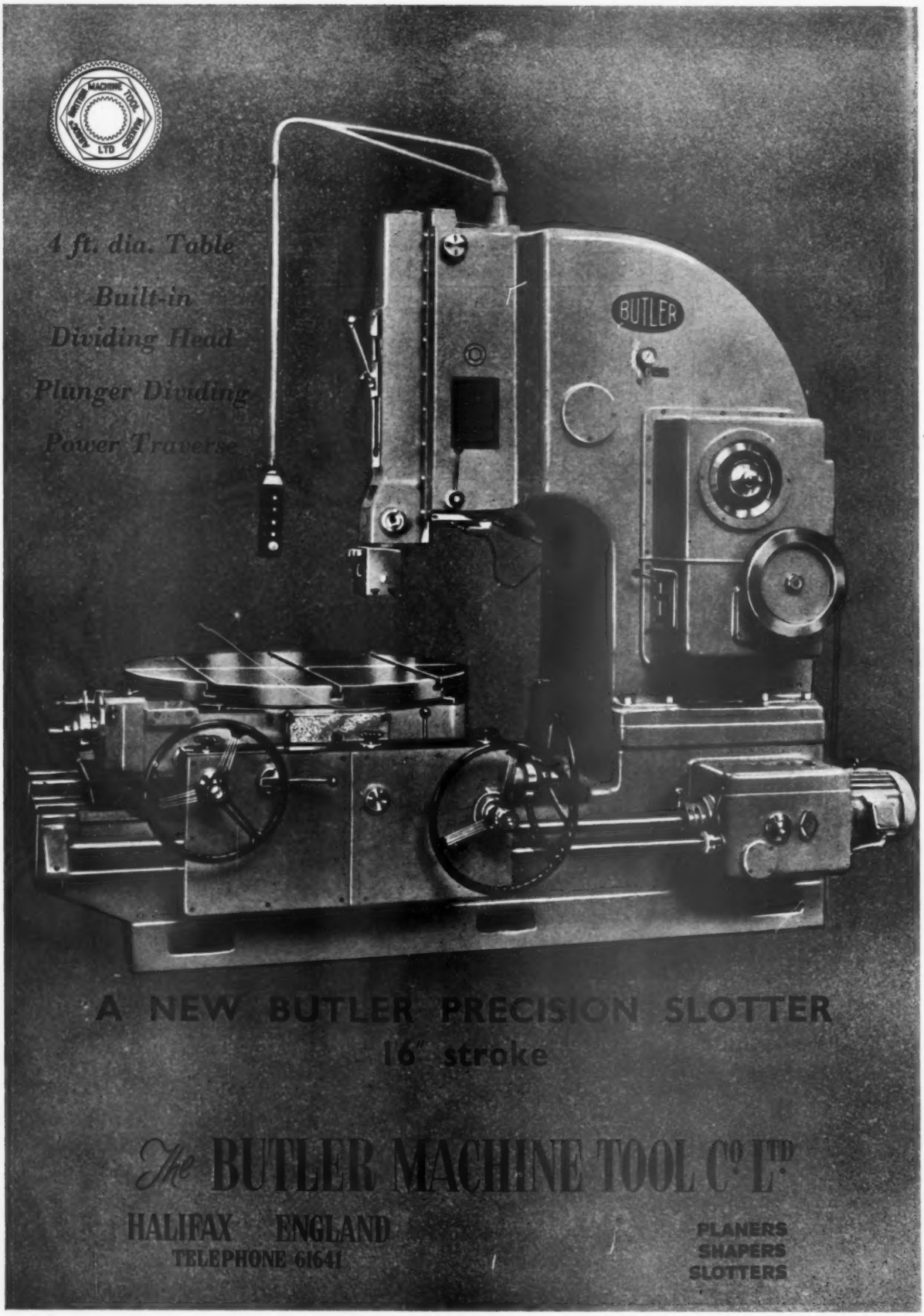
H. W. WARD & CO. LTD

SELLY OAK BIRMINGHAM 29

TELEPHONE SELLY OAK 1131

W 610

International Machine Tool Exhibition, London, 1956 June 22 to July 6 — Stand 17 Grand Hall, Olympia.



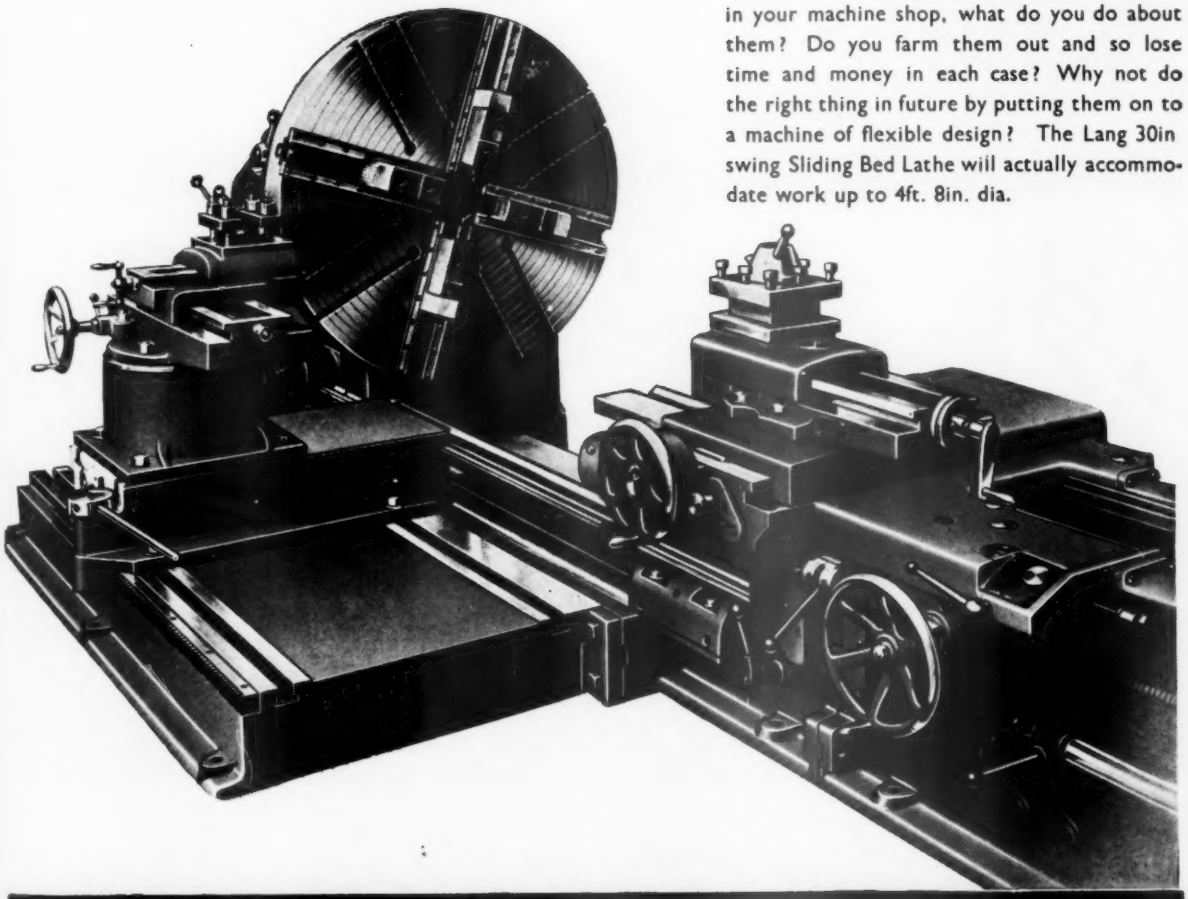
International Machine Tool Exhibition, London 1956 June 22 to July 6 — Stand 11 Grand Hall, Olympia.

Equal to any emergency

LANG

S-L-I-D-I-N-G B-E-D LATHES

When those awkward outsize jobs come along in your machine shop, what do you do about them? Do you farm them out and so lose time and money in each case? Why not do the right thing in future by putting them on to a machine of flexible design? The Lang 30in swing Sliding Bed Lathe will actually accommodate work up to 4ft. 8in. dia.



JOHN LANG & SONS LTD.

JOHNSTONE NEAR GLASGOW

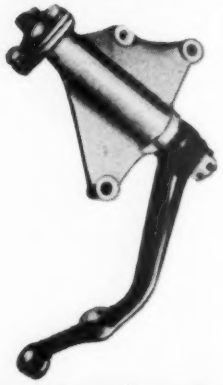
Phone JOHNSTONE 400

LONDON OFFICE
ASSOCIATED BRITISH MACHINE TOOL MAKERS LIMITED
17 GROSVENOR GARDENS S.W.1

L190A

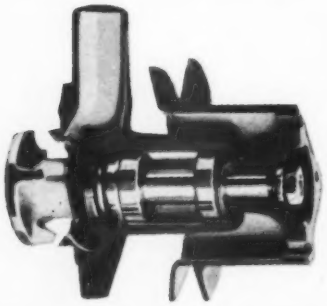
International Machine Tool Exhibition, London, 1956 — June 22 to July 6 — Stand 54 Grand Hall, Olympia.

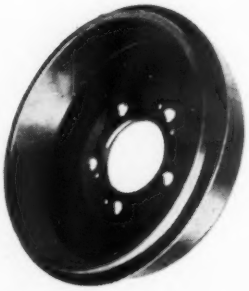
CONSISTENT *ACCURACY* . . .
CONSCIENTIOUS *SERVICE* . .
CONVINCING *PERFORMANCE*.



CONCENTRIC COMPONENTS

Precision Parts that meet the highly specialized requirements of the Car and Commercial Vehicle Industries.





WATER PUMPS · STEERING IDLERS · GEAR CHANGE MECHANISMS · BRAKE DRUMS PUSH RODS · BALL PINS · SHACKLE PLATES, THRUST PLATES & ASSEMBLIES · MACHINED COMPONENTS OF ALL KINDS.

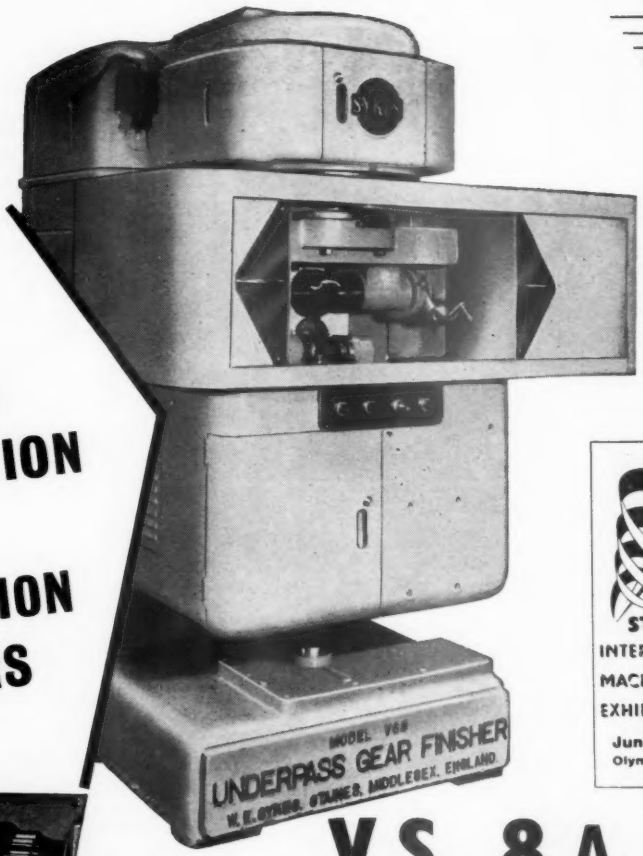
Manufactured in a modern factory specially designed and equipped to produce a better job in less time and at lower cost.

Concentric
MANUFACTURING CO. LTD.
TYBURN ROAD. BIRMINGHAM 24

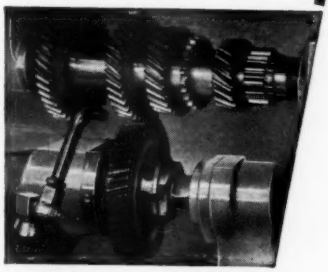
Telephone : EAST 2081·2·3·4·5
Telegrams : "Accelerate" Phone Birmingham

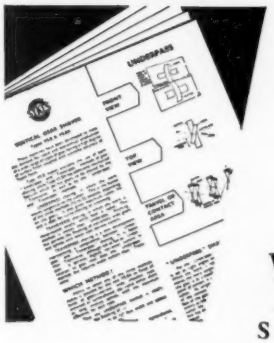
SYKES

for
RAPID
PRODUCTION
of
PRECISION
GEARS



STAND 62
INTERNATIONAL
MACHINE TOOL
EXHIBITION 1956
June 22-July 6
Olympia · London





VS.8A

UNIVERSAL ROTARY GEAR SHAVING MACHINE

The VS.8A will shave gears by the Underpass, Transverse and Traverpass systems.

These rapid and economical methods of precision gear production need no particular skill. Concentricity and tooth profile accuracy are improved and a high degree of finish is obtained.

Profile modifications — both Axial and Transverse — can be readily incorporated and Shaving can be carried out close up to a shoulder where grinding would be impossible.

← **This useful brochure on Gear Shaving sent on request.**

You are cordially invited to inspect these machines in operation at our works.
(*Waterloo to Staines 30 minutes*)

W. E. SYKES LIMITED

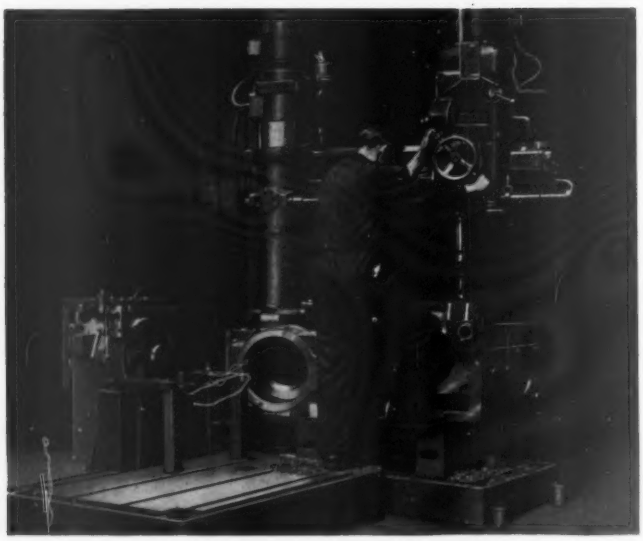
STAINES · MIDDLESEX · ENGLAND

'Phone: STAINES 4281 (6 *lines*) *'Grams*: 'SYKUTTER, STAINES'

Canada : Sykes Tool Corporation Ltd., 123/131 York Street, Toronto

Australia : W. E. Sykes Ltd., Mascot, Sydney, N.S.W.

they go to Town ...



In the production line,
this A.E.I. type
Radial is drilling and tapping
¾" B.S.F. and 1" B.S.P.
holes in a Crawler Tractor
gear box.
Three way baseplate set-up
uses machine to
its maximum capacity.

at Marshall Sons and Co. Ltd.

GAINSBOROUGH—LINCS

In the toolroom, an
A.E.I. type Radial is used
for accurate work,
in this case drilling a
jig plate, the holes having
been plotted
previously on a jig-boring
machine.

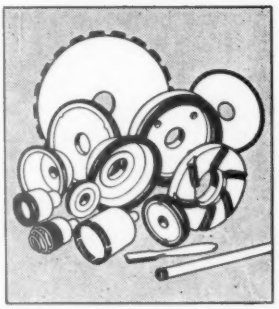
ESTABLISHED · 1903

FRED^K TOWN & SONS LTD

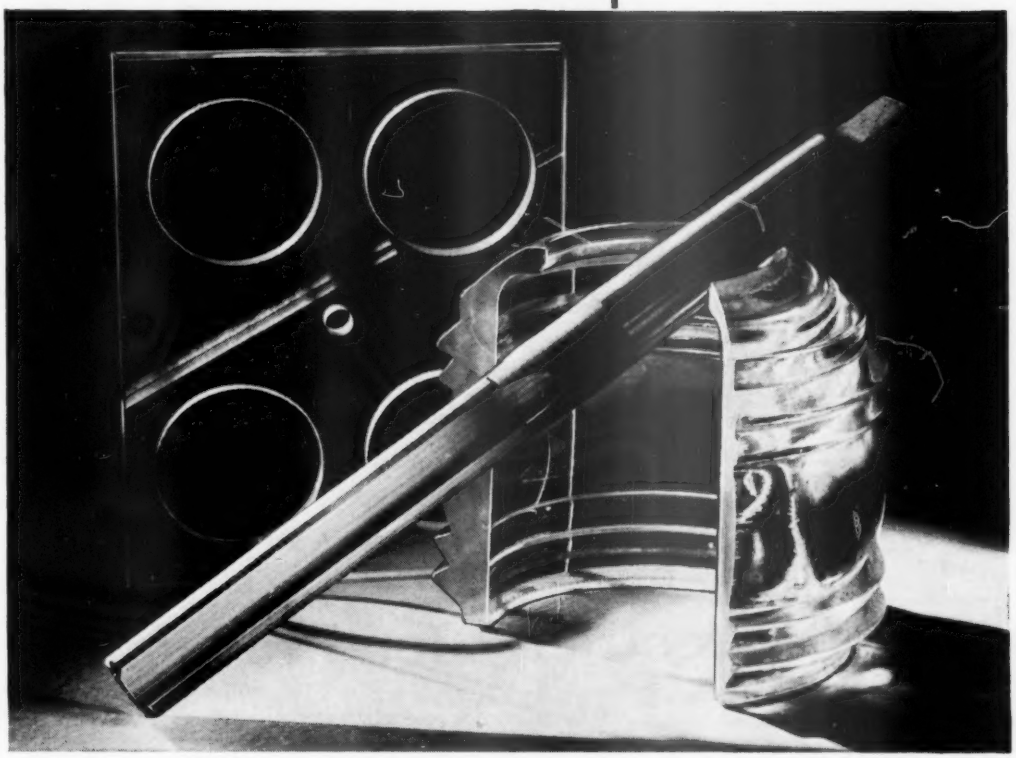
HALIFAX · YORKS

T.8

NEVEN *Diamond* TOOLS



cut, drill or grind any hard material



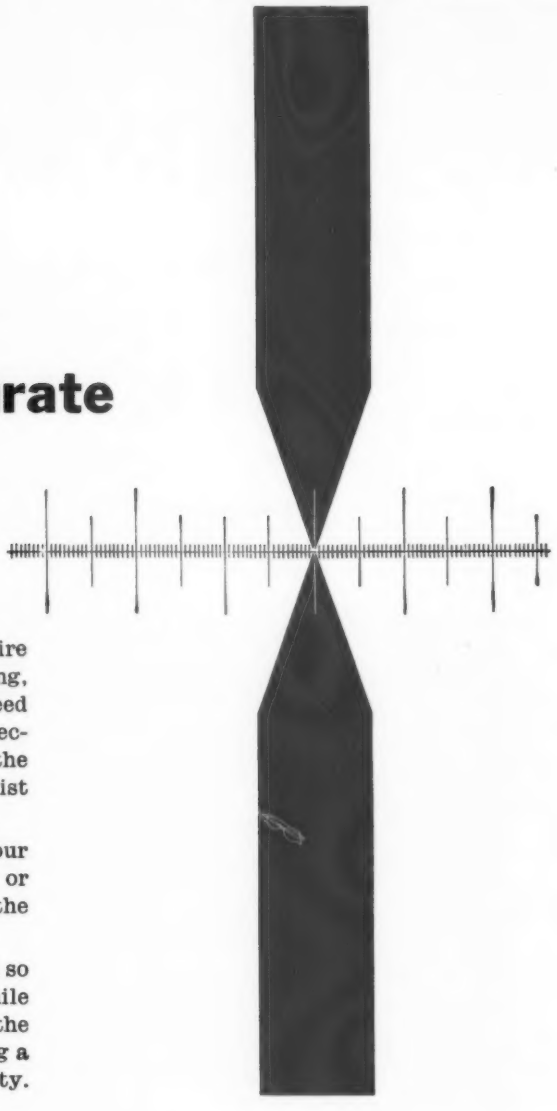
CERAMICS, TUNGSTEN CARBIDE, GLASS, QUARTZ, STONE, GRANITE

MINERALS, SLATE, SHELL, REFRACTORIES AND ALL HARD METALS

IMPREGNATED DIAMOND PRODUCTS LTD·GLOUCESTER

Telephone 21164·Telegrams·Impreg·Gloucester.

Nothing more accurate than Electronics



If at some stage in your process you require high operating speeds in sorting, batching, counting, computing, accurate and wide speed control, or non-destructive testing and inspection, electronic equipment can do it. If the appropriate equipment does not already exist it can be designed and made for your job.

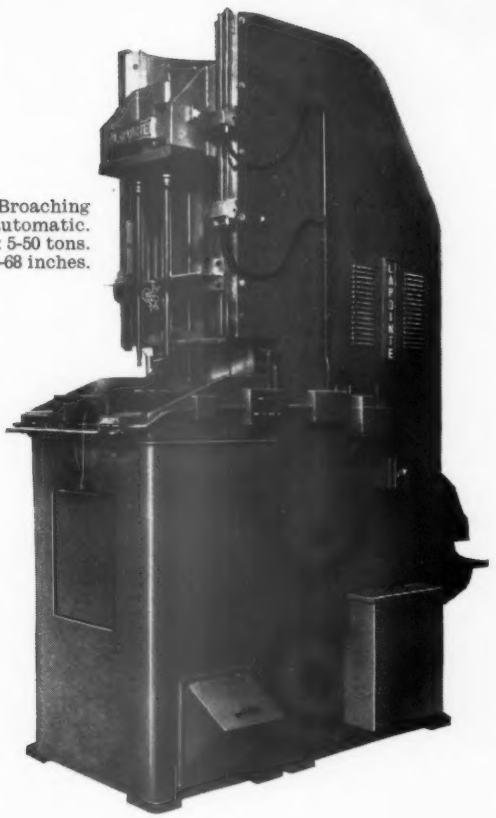
Once installed it will last as long as your machines and need little maintenance or attention. It will consistently raise the standard of your products.

Because it does its work so quickly and so well you will find production rising while overheads are reduced. This is only one of the many ways in which electricity is playing a vital part in the drive for higher productivity.

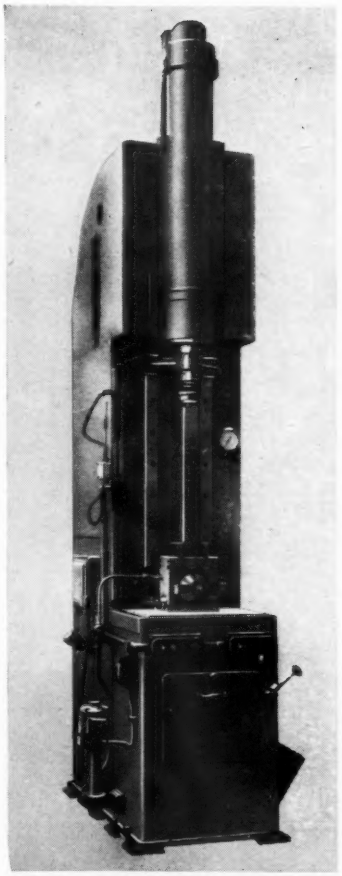
Electricity for Productivity

Ask your ELECTRICITY BOARD for advice and information, or get in touch with E.D.A. They can lend you, without charge, films about the uses of electricity in industry. E.D.A. are also publishing a series of books on Electricity and Productivity. Titles now available are Electric Motors and Controls. Higher Production, Lighting in Industry, Materials Handling, and Resistance Heating. Price 8/6, or 9/- post free.

Issued by the
British Electrical Development Association
2 Savoy Hill, London, W.C.2



Vertical Internal Broaching Machines, fully automatic.
Capacity: 5-50 tons.
Broach length: 42-68 inches.



Vertical Internal/External Broaching Machines.
Capacity: 2½-15 tons.
Stroke: 24, 30, 36 inches.

Come to

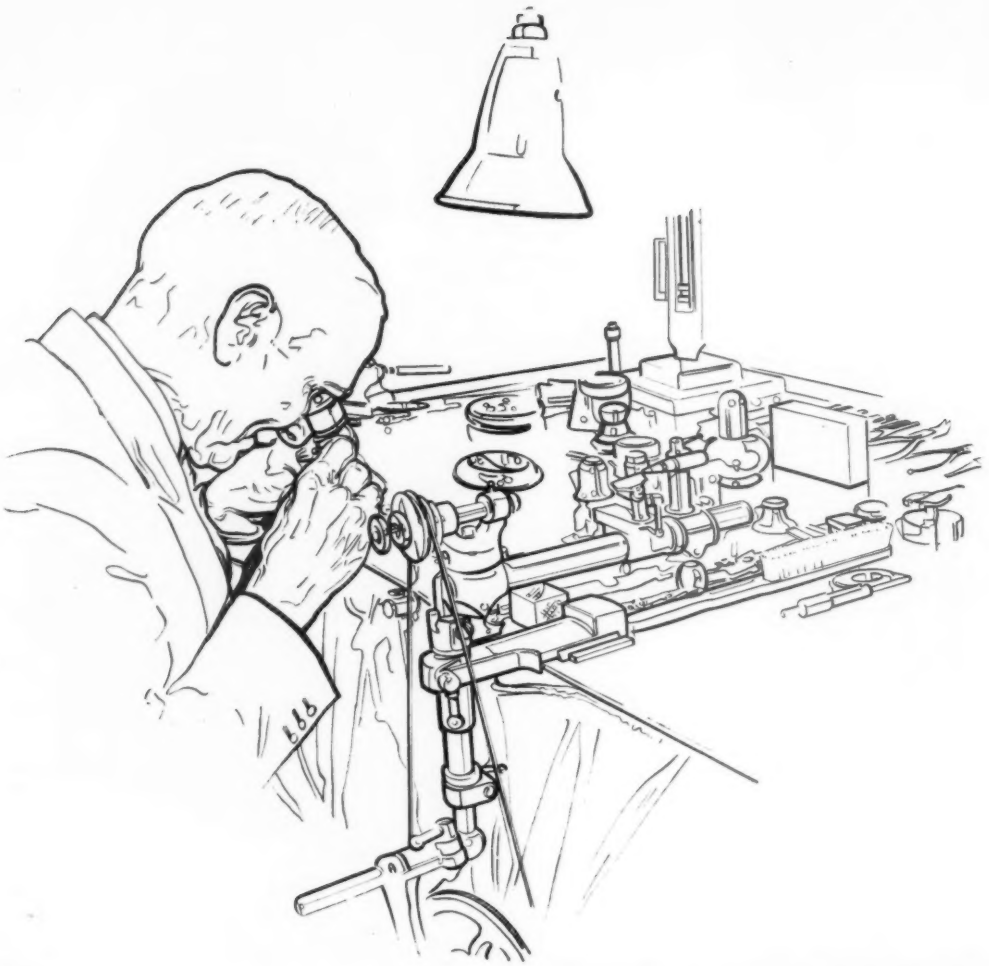
LAPOINTE

for better broaching

BRITISH MADE

THE LAPOINTE MACHINE TOOL CO. LTD
OTTERSPOOL WATFORD-BY-PASS WATFORD HERTS
TEL: GADEBROOK 3711 (4 LINES) CABLES: LAPOINTE WATFORD
Also
The Lapointe Machine Tool Company Hudson, Mass. U.S.A.

INTERNATIONAL MACHINE TOOL EXHIBITION
Olympia, June 22 - July 6, 1956
STAND No. 63



the watchmaker's diamond

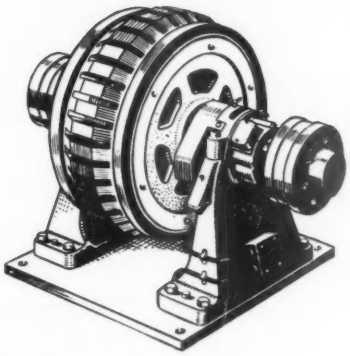
Modern watch-cases require high standards of finish combined with low manufacturing costs. By plunge cutting with the Diatipt Tools illustrated in the insert, the required finish is produced at high production rates.

LM VAN MOPPES & SONS (DIAMOND TOOLS) LTD
BASINGSTOKE · HAMPSHIRE · ENGLAND

Telephone : Basingstoke 1240
Telegrams : Diatipt Basingstoke

TRADE MARKS · DIATRU · DIANYF · DIATUF · DIATIPT · DIADUST · DIAFORM · DIADEX · DIATHREAD · DIATORC

Automation...



ELECTRONICALLY CONTROLLED

VARIABLE SPEED DRIVES

WITH THE

HEENAN-DYNAMATIC COUPLING

AND

HEENATRON UNIT

SPECIALISTS IN

AUTOMATION BY VARIABLE SPEED
AUTOMATIC CONTROLS
SYNCHRONISED DRIVES
CONVEYOR DRIVES (SINGLE OR MULTIPLE)
PROCESS MACHINE DRIVES
REELING DRIVES, ETC.

We would welcome the opportunity of discussing your drive problems — we think we could help you

HEENAN & FROUDE LTD Engineers WORCESTER

Telephone—Worcester 3461 (10 lines) Telegrams—Heenan, Worcester

When replying to advertisements please mention the Journal

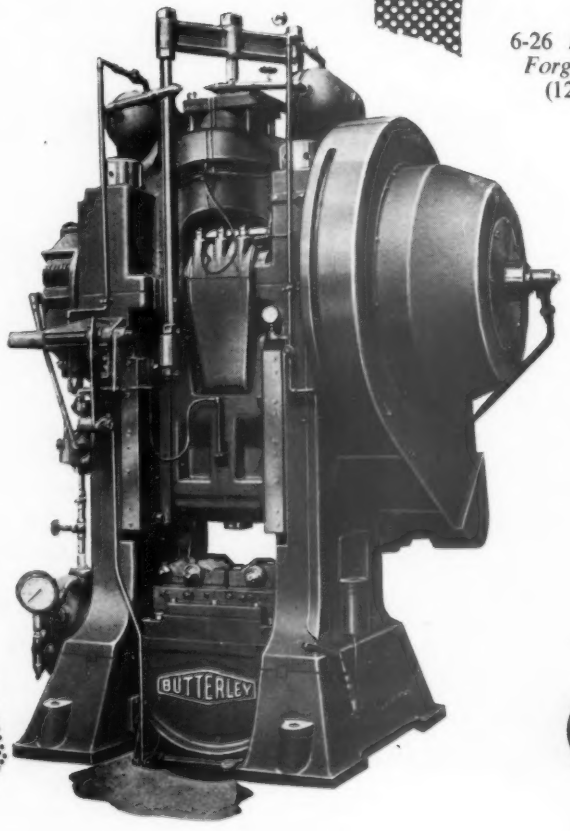
SHEET METAL MACHINERY

by

BUTTERLEY

The Butterley range of sheet metal machinery includes geared and ungeared power presses, press brakes and general machinery for the hot and cold working of metals.

All castings are made by the Meehanite process in the Company's own well-equipped foundry and behind the high quality of workmanship there, and in the machine, fitting and assembly shops lie many years of experience.



6-26 *High-speed Forging Press* (120 *tons*)

Full details of Butterley Sheet Metal Machinery supplied on request . . .

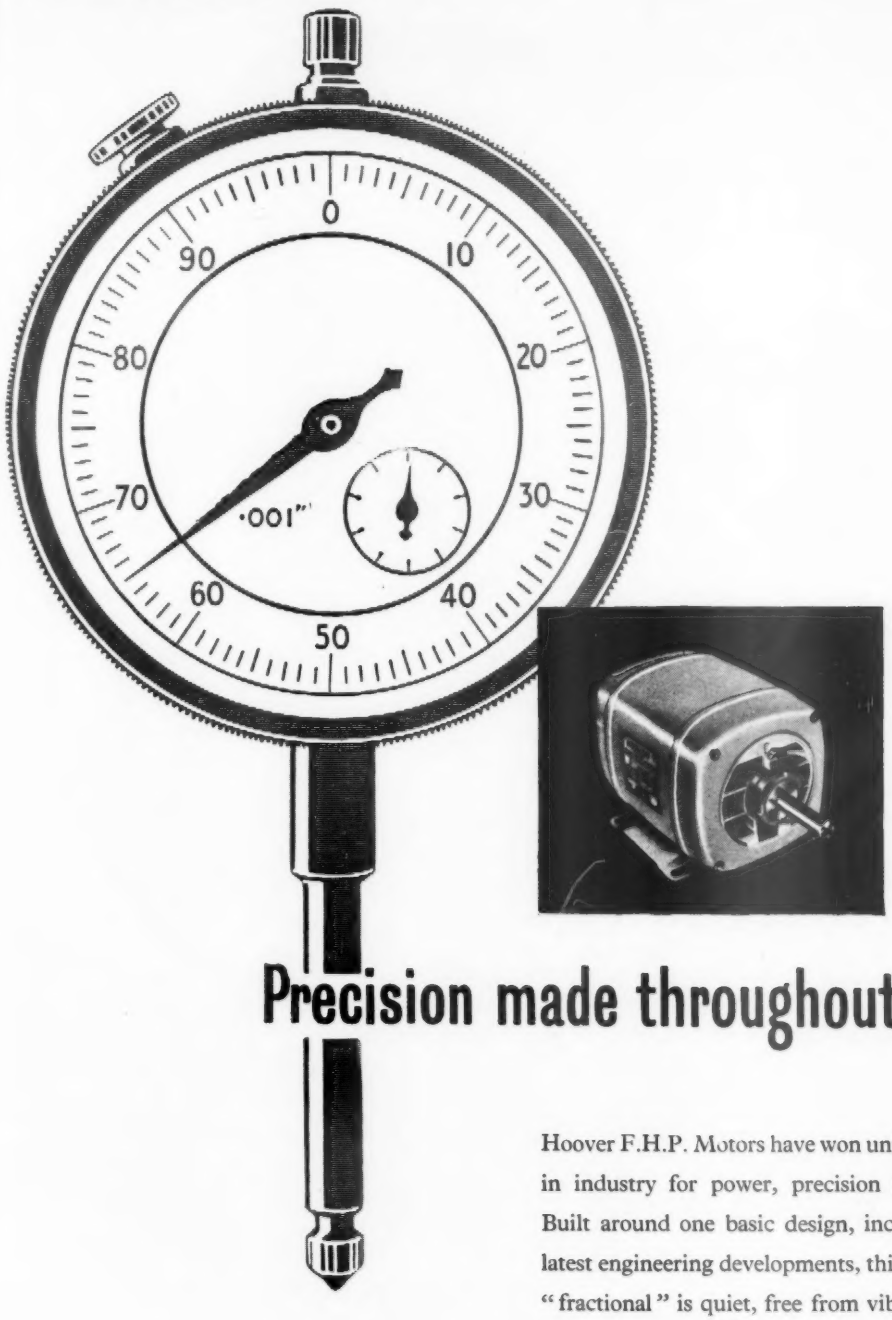
THE BUTTERLEY COMPANY LIMITED

RIPLEY . DERBY . ENGLAND *Telephone : RIPLEY 411 (9 lines)*

London Office : 9 UPPER BELGRAVE ST., S.W.1

Telephone : SLOane 8172/3

SM 12



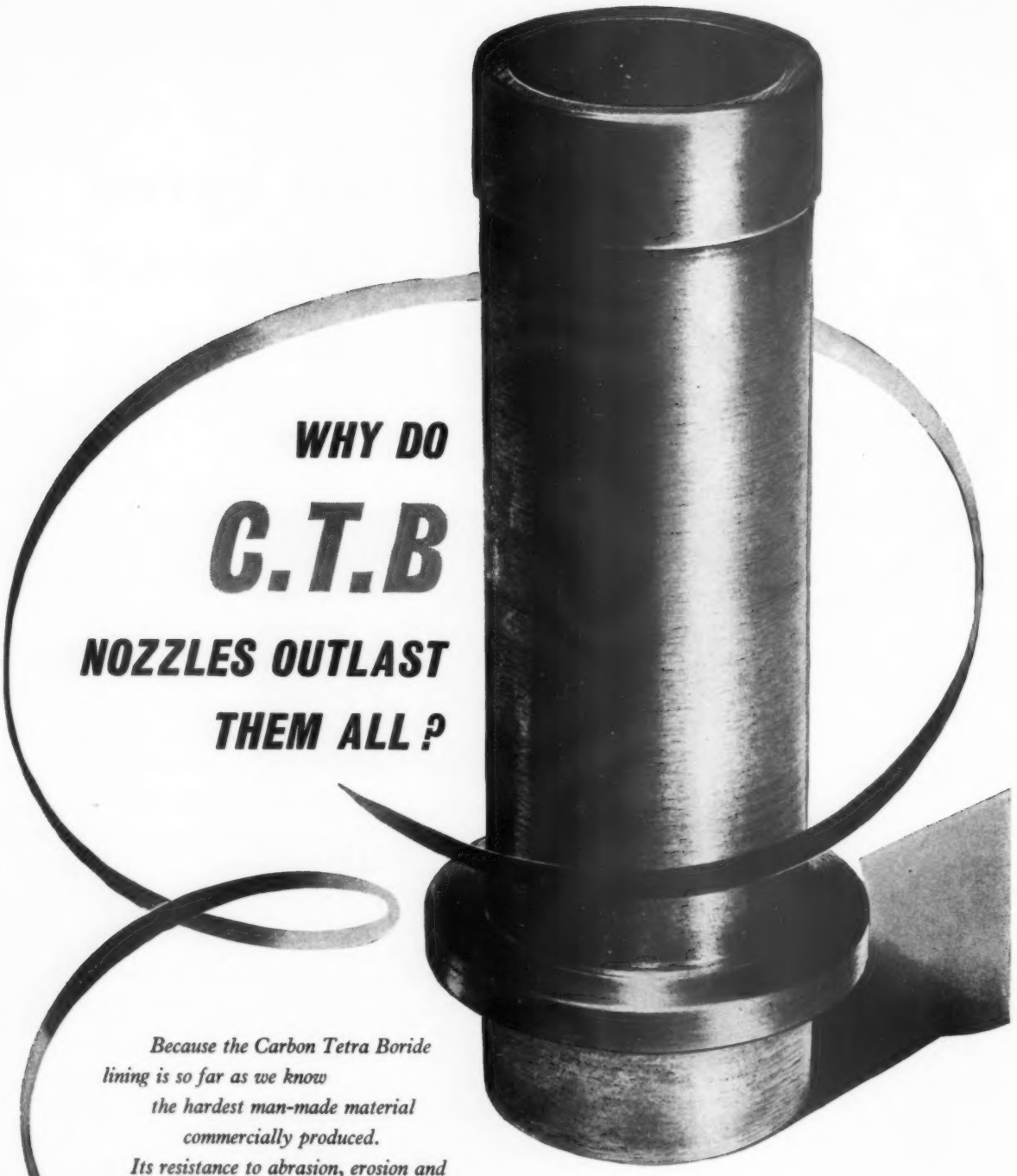
Precision made throughout

Hoover F.H.P. Motors have won universal recognition in industry for power, precision and performance. Built around one basic design, incorporating all the latest engineering developments, this compact Hoover "fractional" is quiet, free from vibration and has an exceptionally effective cooling system.

Competitive in price, all Hoover F.H.P. Motors are backed by the unique Hoover service plan. For full technical information please write to:

HOOVER LIMITED

Industrial Products Department · CAMBUSLANG · LANARKSHIRE · SCOTLAND



WHY DO

C.T.B

NOZZLES OUTLAST THEM ALL?

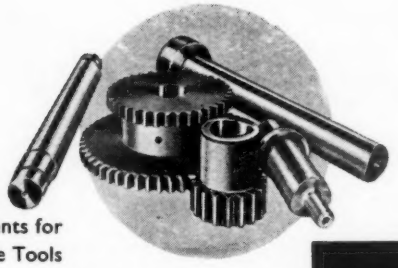
Because the Carbon Tetra Boride lining is so far as we know the hardest man-made material commercially produced. Its resistance to abrasion, erosion and chemical action is greater than that of any other hard metal.

Glostics Ltd

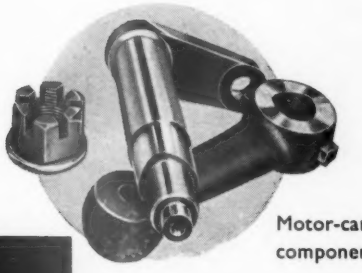
AGENTS · IMPREGNATED DIAMOND PRODUCTS LTD

TUFFLEY CRESCENT · GLOUCESTER

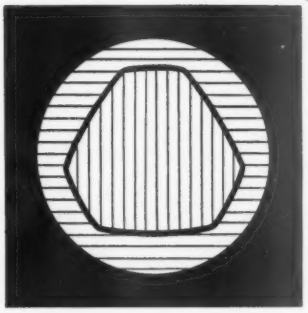
Eliminate Splining Problems with the **POLYGON** Profile!

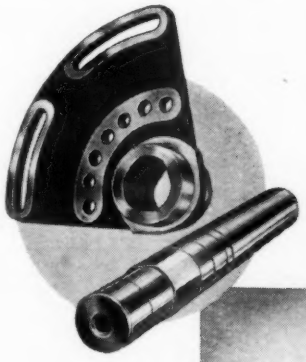


Components for Machine Tools

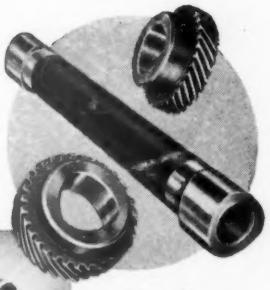


Motor-car steering components

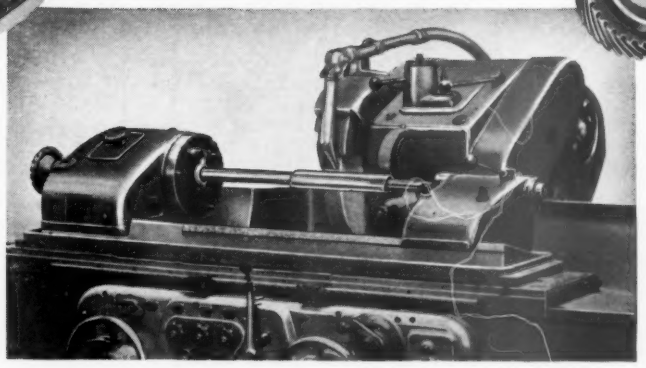




Cam with POLYGON fit



Parts for Textile Machines



MANURHIN

POLYGON UNIVERSAL PROFILE & CYLINDRICAL GRINDING MACHINES

SOLE U.K. DISTRIBUTORS: *Send for technical details*

DOWDING & DOLL LTD

346 KENSINGTON HIGH STREET, LONDON, W. 14

Telephone: WESTERN 8077 (8 lines) *Telegrams*: ACCURATOOL HAMMER LONDON

78

ACCESSIBILITY

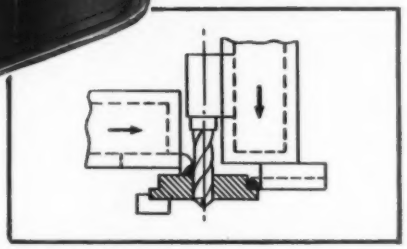
AN OUTSTANDING FEATURE OF THE NEW Vertimax 18" SWING PRODUCTION LATHE

Other important details of this new Vertimax

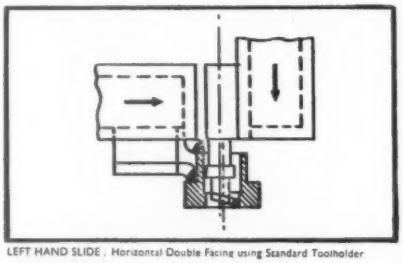
- 10 spindle speeds
- Grouped controls
- Air chucking or special clamping fixtures
- Hydraulic Tool Slides
- Fully automatic or semi-automatic operation
- Self-contained electrical & hydraulic compartments

An ideal lathe for machining pipe flanges, starter rings, gear blanks, etc.

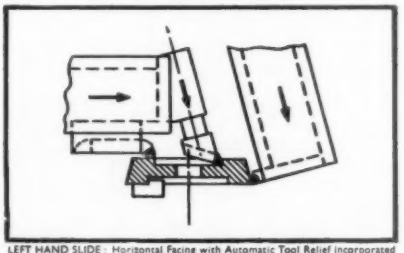
THE VERSATILITY OF THIS NEW VERTIMAX IS ILLUSTRATED BY THESE TYPICAL TOOL LAYOUTS



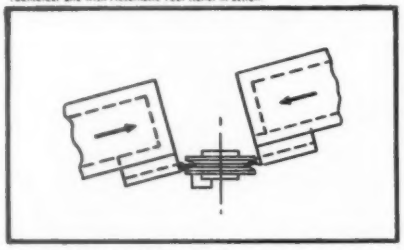
LEFT HAND SLIDE : Horizontal Facing.
RIGHT HAND SLIDE : Vertical Drilling and Turning with Standard Toolholders.



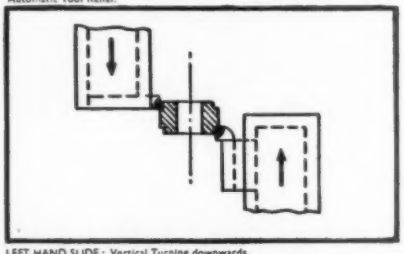
LEFT HAND SLIDE : Horizontal Double Facing using Standard Toolholder.
RIGHT HAND SLIDE : Vertical Deep Boring using Standard Retracting Toolholder and with Automatic Tool Relief in action.



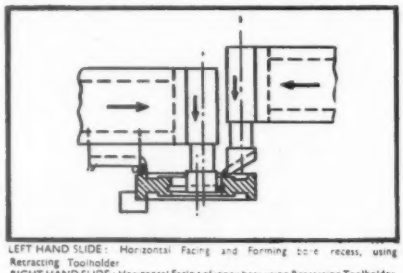
LEFT HAND SLIDE : Horizontal Facing with Automatic Tool Relief incorporated in Standard Toolholder, and recessing with Standard Angular Retracting Toolholder. RIGHT HAND SLIDE : Turning Angular outside diameter with Automatic Tool Relief.



LEFT HAND & RIGHT HAND SLIDES : Turning Angular faced recess using Standard Toolholders with Automatic Tool in action in both cases.



LEFT HAND SLIDE : Vertical Turning downwards.
RIGHT HAND SLIDE : Vertical Turning upwards using Standard Toolholder Automatic Tool Relief in action in both cases.



LEFT HAND SLIDE : Horizontal Facing and Forming bore recess, using Retracting Toolholder.
RIGHT HAND SLIDE : Horizontal Facing of inner boss using Retracting Toolholder.

CHARLES CHURCHILL & CO. LTD.

COVENTRY ROAD, SOUTH YARDLEY, BIRMINGHAM

BRANCHES

London: Walnut Tree Walk, Lambeth North, S.E.11
Glasgow: Earl Haig Road, Hillington.
Newcastle: Scotswood Road, 5.
Manchester: St. Simon Street, Salford, 3.

PRODUCTION
WAS ALL AT SEA . . .
until we called in KING
(and got things moving)

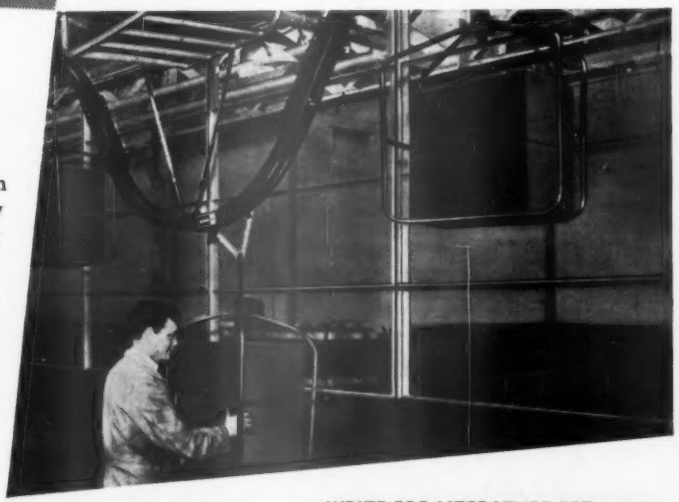
BUT it's plain sailing when **KING** mechanical handling equipment replaces costly time-wasting man-handling. **KING** equipment has worked little miracles in speeding production. Perhaps it can answer your problems, too. *Our representative will call on you—anywhere in the world.*

22 YEARS OF RESEARCH AND DEVELOPMENT

Since 1934 KINGS *have maintained :—*

★ A Research, Development and Demonstration Department. It has been responsible for many outstanding developments in materials handling technique.

★ An Advisory Service which will help you to plan your factory and make the best use of mechanical handling equipment.



STREAMLINE
YOUR PRODUCTION WITH

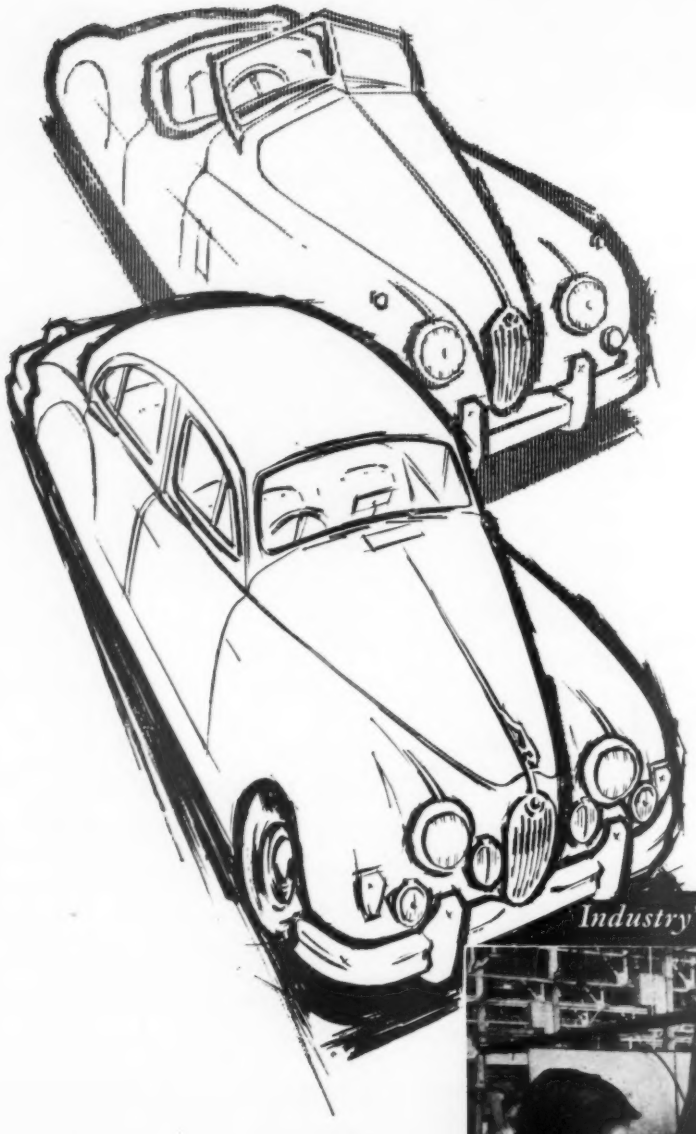
KING
REGISTERED TRADE MARK

WRITE FOR LITERATURE SET 18

CONVEYORS · CRANES · PULLEY BLOCKS

Covered by British and Foreign Patents

GEO. W. KING LTD., ARGYLE WORKS, STEVENAGE, HERTS. TEL: STEVENAGE 440.



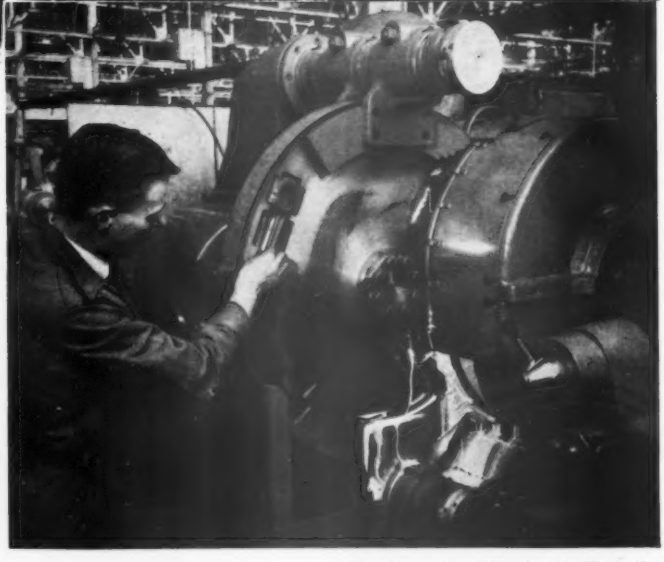
JAGUAR

accelerates production with

SNOW

DUPLEX DISC GRINDER

Industry's biggest names use **SNOW!**



By installing a Snow duplex disc grinder, Jaguar Cars Limited boost output of connecting rods to four per minute (a 900% increase).

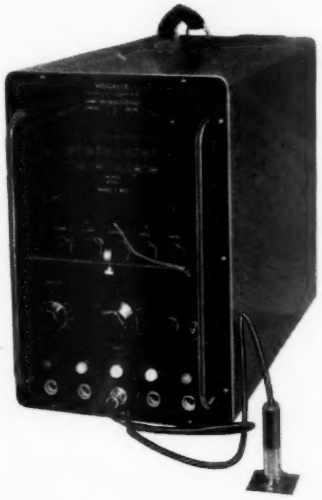
Photo by courtesy of Metalworking Production

SNOW & CO. LTD. *Machine Tool Makers* **STANLEY ST. SHEFFIELD 3**

LONDON *58 Victoria Street, S.W.1.* **BIRMINGHAM** *Daimler House, Paradise Street*

DAWE ELECTRONIC INSTRUMENTS

increase production and ensure efficiency!



VISIGAUGE Type 1107

for measuring the thickness of materials from one side. The actual thickness is read directly from a calibrated screen on the cathode-ray tube. Eminently suitable for use where large areas of metal have to be held to within accurate thickness limits . . . also for detecting lack of bond and internal defects.

Range: 0.015″ to 0.3″ of steel.

STROBOFLASH Type 1200

One of our range of electronic stroboscopes. Permits observation of rotating, reciprocating and vibrating mechanisms in slow motion without physical contact. Speed measurements are given as a direct reading.

Range: 250—18,000 r.p.m.

DYNAMIC BALANCING MACHINE

Type 1250

for the rapid and accurate location and measurement of unbalance in rotating parts or assemblies A new versatile instrument (Type 1251) designed to give greater flexibility of application is available.

Technical data from:- **DAWE INSTRUMENTS LTD.**

99, UXBRIDGE ROAD, EALING, LONDON, W.5 : EALING 6215

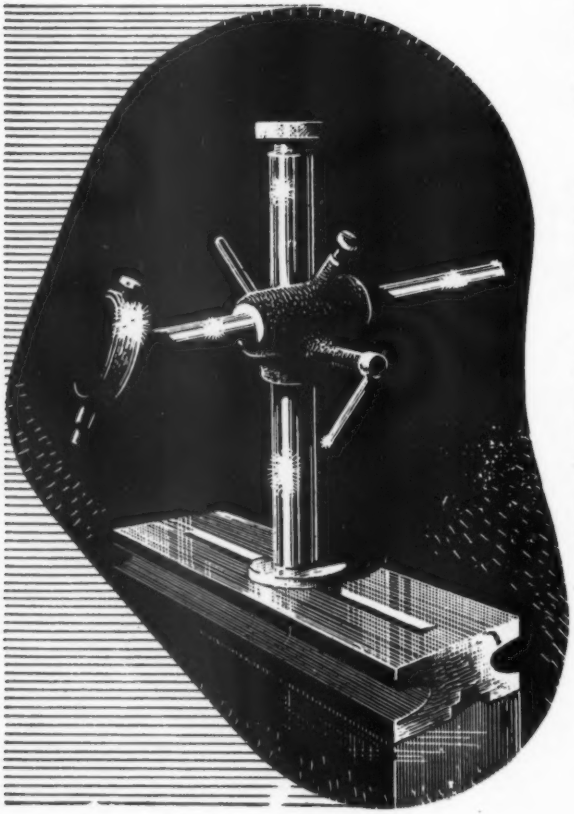
or from your Regional Agent:

Midlands	North of England	Cheshire	Scotland	West of England	Northern Ireland
Hawnt & Co., Ltd., 59, Moor Street, Birmingham, 4 *Central 6871*	Farnell Instruments Ltd., 15, Park Place, Leeds, 1 *Leeds 32958*	F. C. Robinson & Ptnrs., 122, Seymour Grove, Old Trafford, Manchester *Chorlton 5366*	Land, Speight & Co., 73, Robertson Street, Glasgow, C.2 *Central 1082*	Mr. R. H. Pugsley, 37, Maytree Avenue, Headley Park, Bristol 3 *Bristol 6-1009*	James Lowden & Co., 11, Middlepath Street, Belfast *Belfast 57518*

We welcome your enquiries

FOR ALL KINDS OF

JIGS · FIXTURES & GAUGES



PRESS TOOLS · MOULDS AND SPECIAL PURPOSE MACHINES

Our commitments are heavy but we welcome an opportunity to study your requirements for inclusion in our production programme where possible.

Up-to-date shops specially laid out and equipped for making, on a production basis, every type of precision ground gauges; limit snap, form, calliper, taper and special purpose gauge, as well as jigs and fixtures of all kinds, press tools moulds and special purpose machines. Highest class workmanship and accuracy guaranteed.

Guaranteed
Precision
Accuracy

G.P.A.

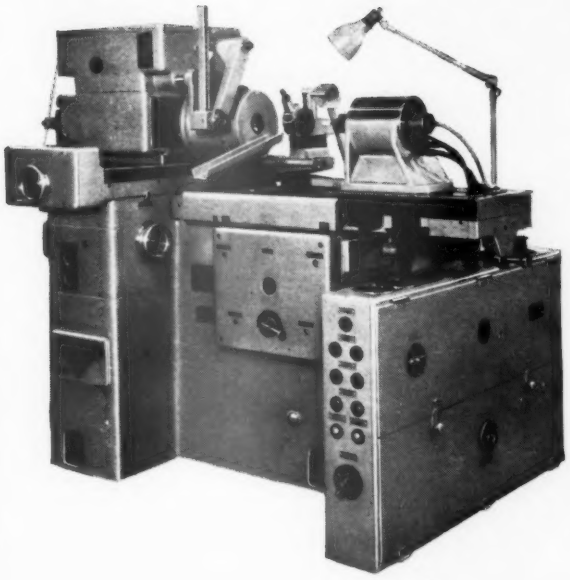
G.P.A. TOOLS & GAUGES LIMITED

HARPER ROAD · WYTHENSHAWE · MANCHESTER

Phone:- **WYTHENSHAWE 2215**

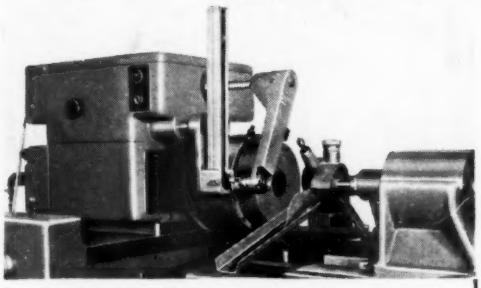
Grams: **PNEUTOOLS, PHONE**

VOUMARD



No 3 INTERNAL GRINDER

This latest addition to the range of Voumard Internal Grinders is the result of many years combined research and experience devoted solely to the building of high precision, high production Internal Grinding Machines.



Showing Automatic Loading Unit, available to order.

SPECIFICATION

Bore diameters	$^{1}/_{16}$" to 2"
Bore depths up to	3"
Max. length of workpiece using steady	18"
Height of Centres	$6\,^{5}/_{16}$"
Number of workspindle speeds	5 (250-1200 r.p.m.)
Speed range of grinding spindles	9000-120000 r.p.m.

FEATURES

1 **Rigidity and Precision**
Both the spindle table and the work head table move on precision rollers running on hardened track ways. This system ensures rigidity and precision by eliminating oil film float and, in the case of the work head, sizing inaccuracies due to slip-stick friction.

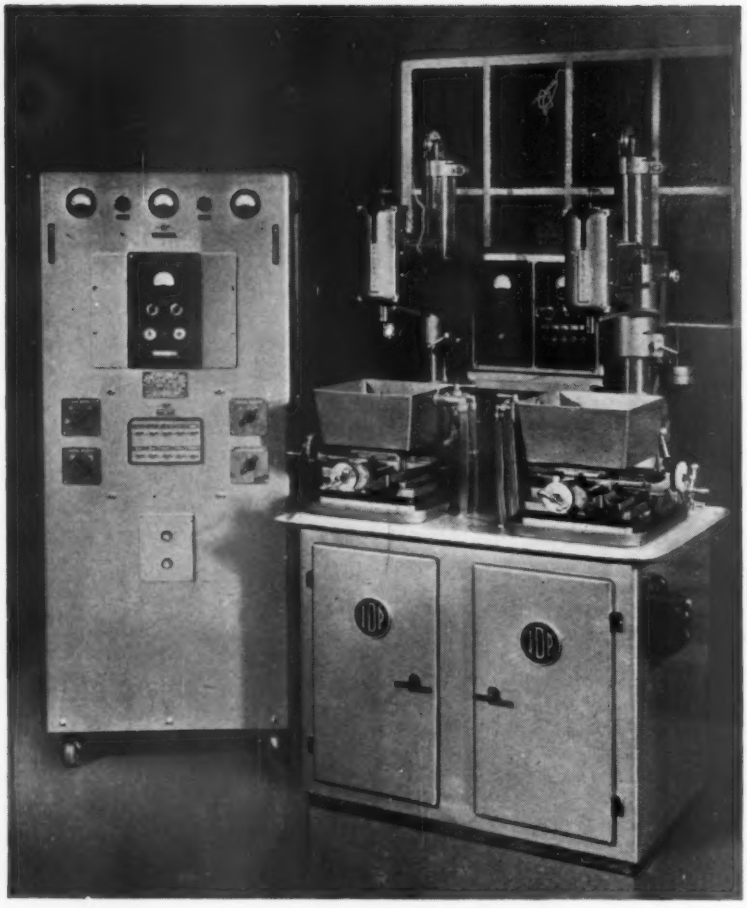
2 **Motor Grinding Spindles**
The use of oil mist lubrication and water cooling permits the construction of High Frequency Motor Spindles without ventilating openings. The spindles are virtually dust and coolant proof and operate for long periods with a minimum of attention. This method of construction also reduces considerably the operating noise of the spindle.

3 **Simple Hydro-Electrical Control**
By eliminating unnecessary control levers, etc., the setting and operating of either semi or fully automatic cycle machines is extremely simple. The main electrical control gear is mounted in a dust-proof cabinet separate from the machine.

SIDNEY JONES

FOR FULL DETAILS WRITE FOR PUBLICATION NO V0.3 TO SOLE AGENTS:

SIDNEY G. JONES LTD · 8 BALHAM HILL · LONDON · S.W.12 TEL. BATTERSEA 3246 · TELEX NO 8723
T A. 9087



For production of all types of dies and form tools.

The leading manufacturers of spark machining equipment in the world, have pleasure in announcing their latest

SPARCATRON Mk. II Model

With double head.

This addition to the Sparcatron range of machines for spark machining has been produced as the result of requests for an equipment for use with large section electrodes to be operated to very close limits, and can be supplied with two heads as illustrated, or with a single head.

The twin head model can be easily worked by one operator, and the heads operated separately, so that production per man hour is doubled.

A further two or more heads may be used in conjunction with the main control unit in some circumstances.

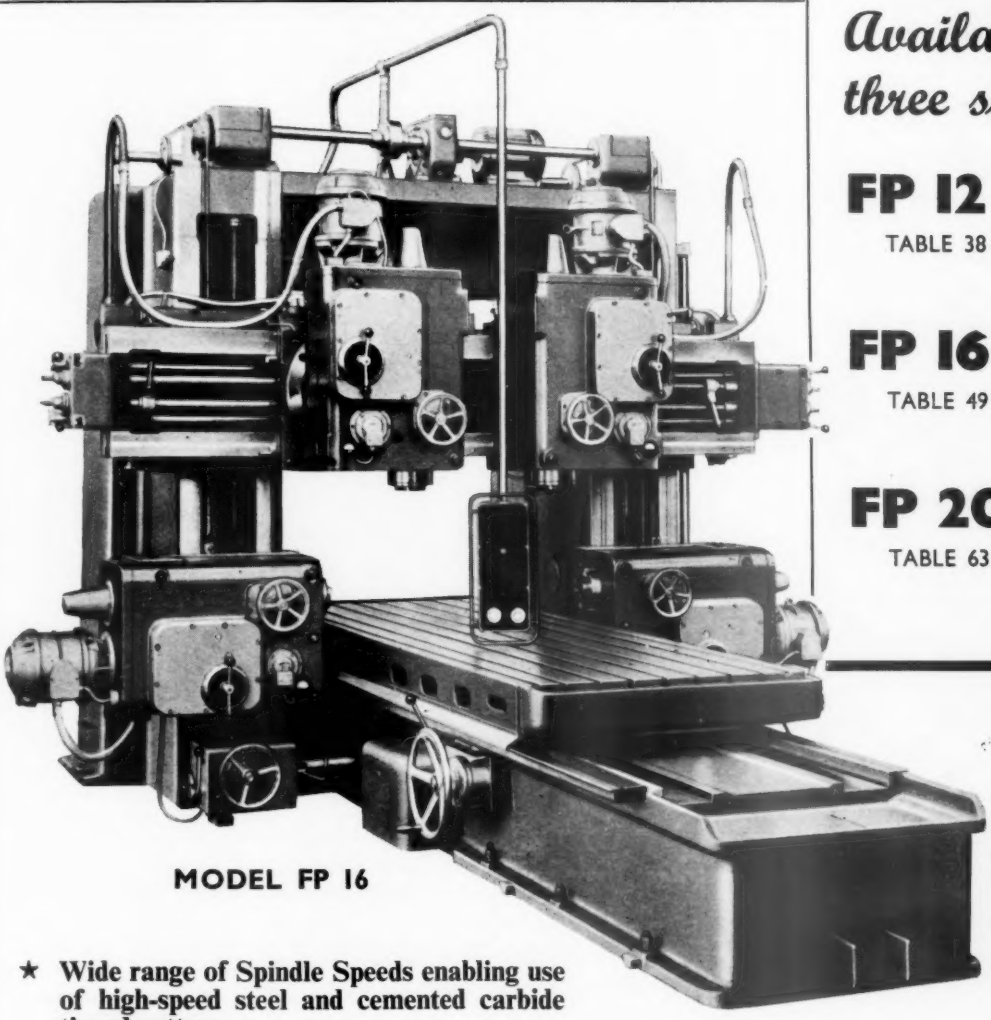
Manufactured by:

IMPREGNATED DIAMOND PRODUCTS LTD., GLOUCESTER, ENGLAND

TELEPHONE 21164 (3 LINES) TELEGRAMS IMPREG GLOUCESTER

ZBROJOVKA

Plano Millers



MODEL FP 16

Available in three sizes

FP 12
TABLE 38 in. by 118 in.

FP 16
TABLE 49 in. by 140 in.

FP 20
TABLE 63 in. by 157 in.

International Machine Tool Exhibition
June 22—July 6, 1956, Olympia, London, Grand Hall, Stand Nos. 45 & 61

- ★ **Wide range of Spindle Speeds enabling use of high-speed steel and cemented carbide tipped cutters.**
- ★ **Table speeds infinitely variable.**
- ★ **Independent drive to individual headstocks, individual drive to table and headstock feeds.**
- ★ **Automatic clamping of cross rail to guide-ways.**

Model FP16 is available for inspection at our showrooms—only a few minutes from London Airport.

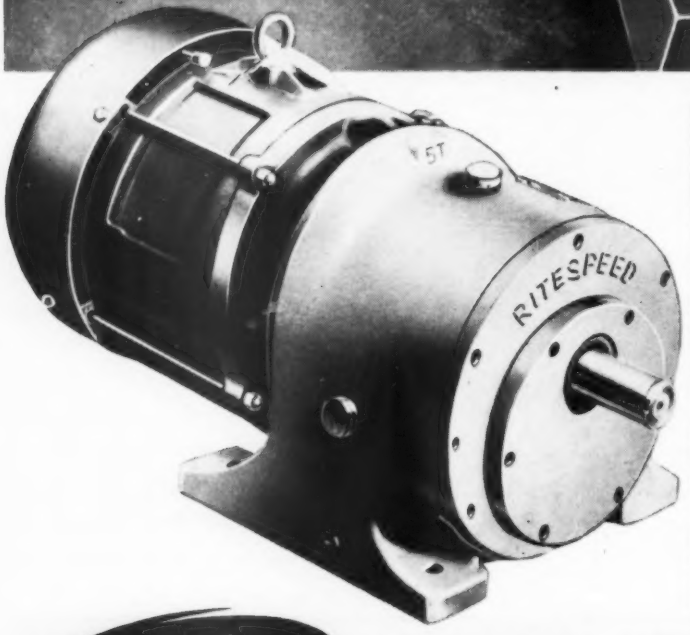
Sole Selling Agents

ELGAR *Machine Tool Company Limited*
HAMPTON ROAD WEST · HANWORTH · FELTHAM · MIDDLESEX
Phone: **FELTHAM 4266.** Cables & Grams: **SHIPMENTS, FELTHAM**

9 Good reasons why...

Crofts RITESPEED

is the drive for productivity!



★ An entirely new development in design embodying a Cartridge Assembly housing the gear train.

★ Unique Cartridge Assembly facilitates interchangeability of High Speed Wheels and Pinions of different ratios providing a wide range of output speeds.

★ Wheels and Pinions to meet all speed requirements are available from STOCK.

★ Adaptable to any make and type of electric motor.

★ Horizontal, Wall or Ceiling Mounting.

★ Positive lubrication system.

★ Compact, robust and of modern appearance.

★ Powers range from Fractional up to 20 H.P. for "Ritespeed" Cartridge Units. Larger Units without cartridge assembly up to 80 H.P. Speed ratios up to 82 to 1.

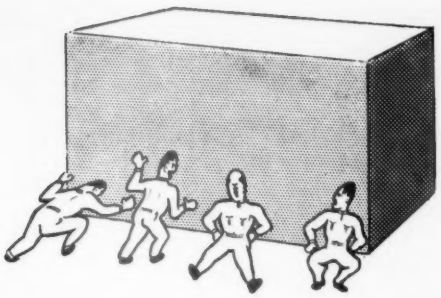
★ IMMEDIATE DELIVERY FROM STOCK UP TO 20 H.P.

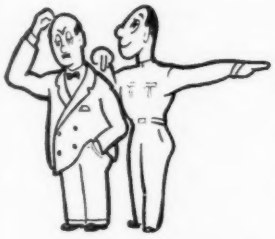
Write for Publication No. 5329/5330/48

Crofts (ENGINEERS) LIMITED BRADFORD 3 ENGLAND

PHONE — 65251 (15 LINES) GRAMS — "CROFTERS BRADFORD

Solve your handling problems





SEE THE LATEST EQUIPMENT FOR SPEEDING PRODUCTION AT BRITAIN'S

MECHANICAL HANDLING

EXHIBITION & CONVENTION

EARLS COURT · LONDON · 9-19 MAY 1956

The greatest display of mechanical handling equipment the world has ever seen, packed with devices for reducing costs and increasing output, takes place at Earls Court in May.

This is the place to solve every materials handling problem. Here you can inspect labour-aiding equipment, large and small, for every industry, light or heavy. Whether your requirements involve only a modest device or a large-scale installation, they can be met.

This exhibition, demonstrating the enormous strides made in handling techniques, is of world-wide importance to all concerned with production —with the achievement of higher output for less cost and effort. At the Convention, experts from many countries will explain their methods for speeding production. Decide now to visit this vital event. Make your plans today and mail the coupon below for fuller details.

The world's largest display of labour-aiding devices in the world's largest exhibition hall.

Over 400,000 square feet of space, showing every type of equipment, large and small, from a simple trolley to elaborate coal-handling gear and ingenious bottling plant.

Something to save time, cost and effort in every industry from mining to milling.

Many working exhibits, with experts to advise on your special problems.

Free consulting bureau and industrial cinema during exhibition hours (10 A.M. *to* 6 P.M. *daily*).

ORGANISED BY 'MECHANICAL HANDLING' — AN ASSOCIATED ILIFFE PRESS JOURNAL

TO: **MECHANICAL HANDLING** . DORSET HOUSE . STAMFORD STREET . LONDON . S.E.1.

Please send the 1956 Exhibition brochure with details of Convention and free season ticket, etc.

NAME .....

ADDRESS .....

67A

grinding . . .

on heavy lathes, and large horizontal or vertical boring machines is best done by Westool Grinders! The Westool range includes models with Slide Rest, Tool-post or Planetary mountings to suit most applications. If you have any special requirements you will appreciate the individual attention which Westool will give your particular problem.

Send now for Illustrated booklet giving further information.

WESTOOL LIMITED

ST. HELEN'S AUCKLAND, CO. DURHAM

Telephone: **West Auckland 317 (6 lines)** *Cables:* **Solenoid, West Auckland**

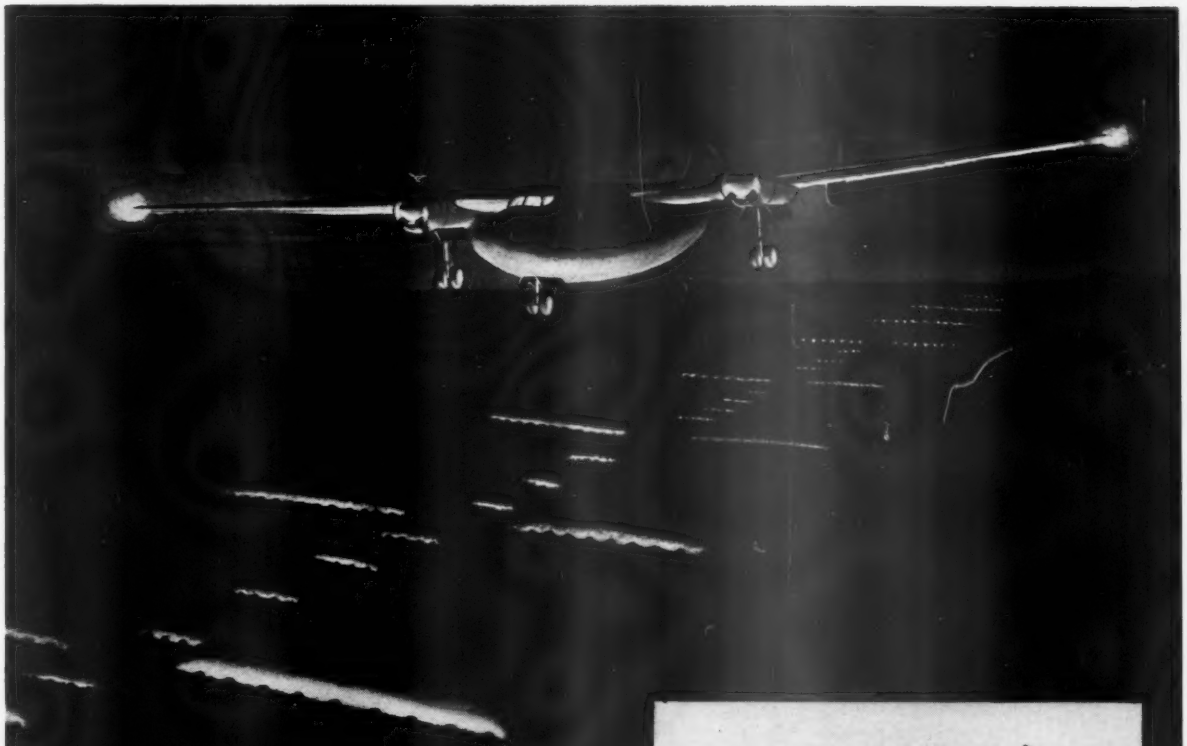
Export enquiries to Export Managers:

Stamm & Partners Ltd., 59 St. Martin's Lane, London, W.C.2

Telephone: **Temple Bar 5383 (10 lines)** *Cables:* **Stamstam, London**

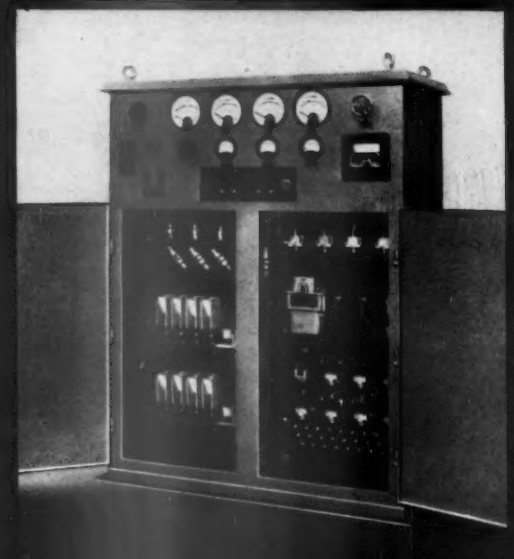
Westool also make Coils · Coil Winding Machines · A.C. and D.C. Solenoids · Transformers · Small Motors · Air Conditioners · Warner Brakes & Clutches, etc.

Tib. 27



carrying a responsible load

Standing by in case of a mains failure and a consequent disastrous break in runway lighting, the nine emergency generating sets at London Airport are controlled by Electro-Dynamic Switchboards and Panels. Sure proof of the trust placed in this outstanding control gear. The panels include audible, local, and remote visible alarm indicators for such emergencies as alternator overloading and engine failure.



A control panel : 50 kVA, 400 volts, 3-phase, 60 cycles.

Energy shaped to industry

ELECTRO DYNAMIC CONSTRUCTION CO LTD

ST. MARY CRAY · KENT

Tel : ORPINGTON 27551. Grams : "ELEDAMIC, ST. MARY CRAY"

Control Gear Works : Bridgwater, Somerset. Tel : Bridgwater 2882. Glasgow Office : 40 Houldsworth St., C.3. Tel : Central 2620

P1429

CHECK 2&3-dimensional forms

with the

PG LTD

UNIVERSAL MEASURING MACHINE

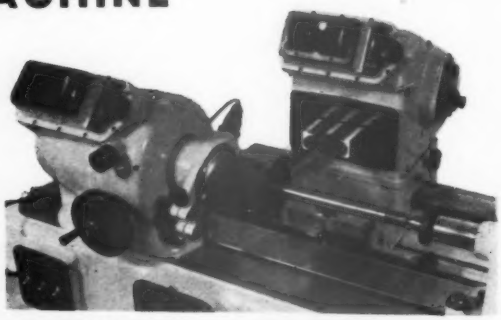
For checking 2 and 3 dimensional cams, gears, thread forms, gap and length gauges, in fact for any component which involves controlled rotary or rectangular measurements.

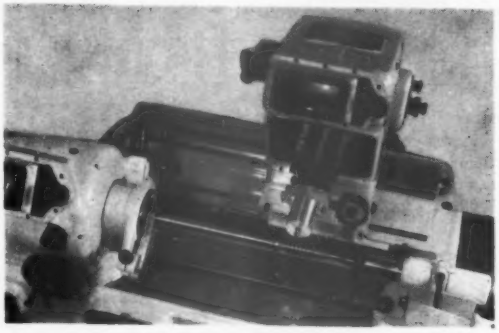
PRINCIPAL DIMENSIONS

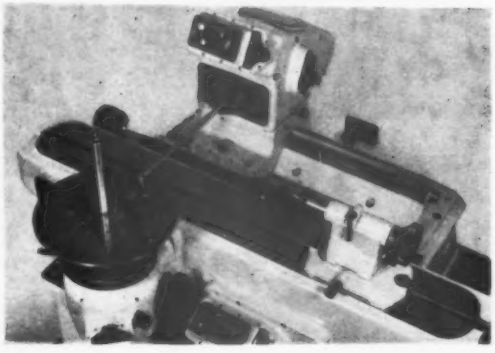
Centre height of optical dividing head mounted horizontally	48"
Maximum diameter, measured with optical dividing head mounted vertically	26"
Maximum distance between centres	20"
Range of measuring head	0-4"
Range of longitudinal slide	12"

PHOTOGRAPHS SHOW :—

1. *Set-up for checking three-dimensional cams. All readings taken on large optical screens for co-ordinates in three directions.*
2. *Thread pitch is measured by using a stylus head allowing lateral float of the ball, indicated on a 0·0001 in. comparator. Measuring head is traversed one pitch between readings, the comparator showing any pitch error.*
3. *Alternative mounting position for the optical dividing head enables the profile of flat cams to be checked. In this set-up an extension stylus is being used.*





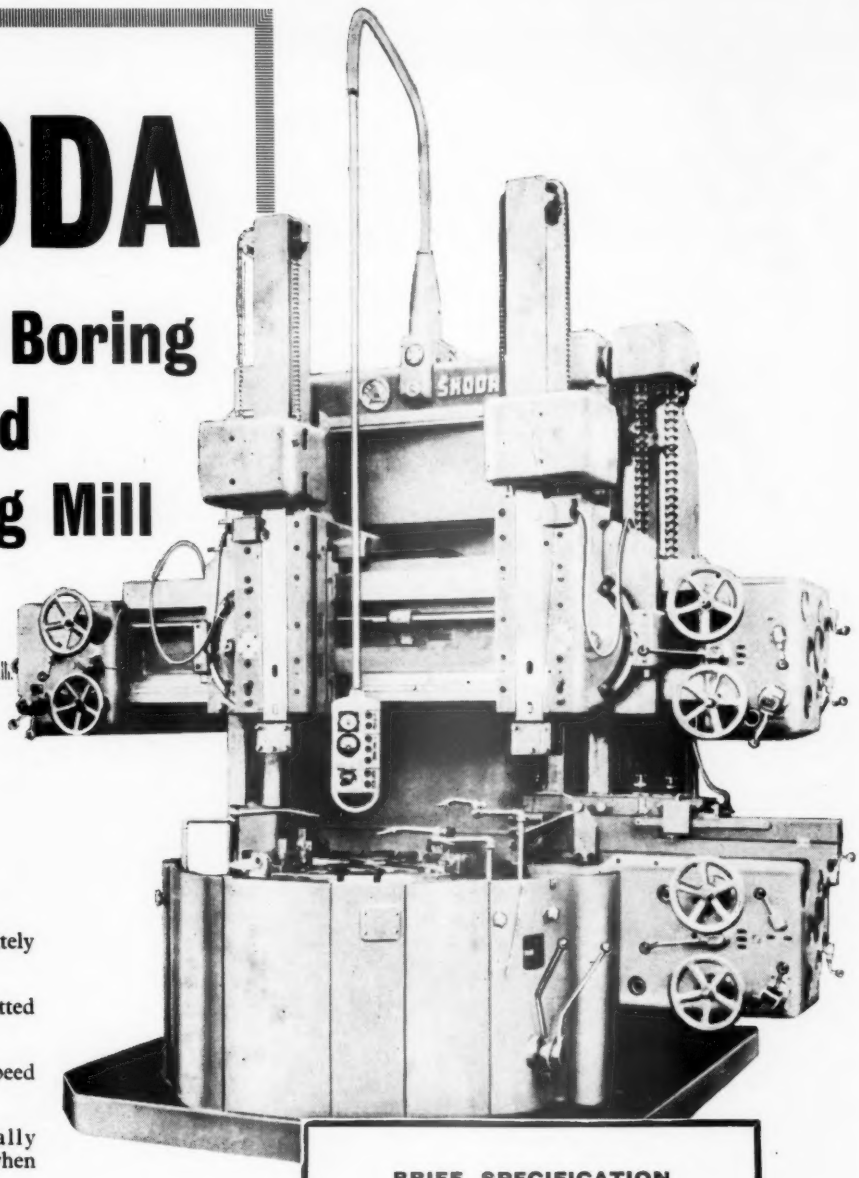


PRECISION GRINDING LTD.
MILL GREEN ROAD, MITCHAM, SURREY
TELEPHONE : MITCHAM 3014

A SUBSIDIARY OF GEORGE H. ALEXANDER MACHINERY LTD., 82-84 COLESHILL ST., B'HAM.
TELEPHONE : ASTON CROSS 3264

SKODA

Vertical Boring and Turning Mill



MODEL SK12 ILLUSTRATED

High table speeds, infinitely variable.

Anti-friction bearings fitted to spindle.

Drive through variable-speed commutator motor.

Cross-rail automatically clamped and unclamped when raising or lowering.

BRIEF SPECIFICATION

Maximum swing with side head	49 in.
Maximum swing without side head	53 in.
Maximum distance between table and rail head toolholder	39 in.
Table diameter	46½ in.
Infinitely variable speed from	3.55-150 r.p.m.
Variable speed motor output	27 kW.
Weight of machine	15,600 kg.

EARLY DELIVERY

Selson MACHINE TOOLS

SOLE AGENTS

The Selson Machine Tool Co. Ltd

CUNARD WORKS, CHASE ROAD, NORTH ACTON, LONDON, N.W.10

Telephone: Elgar 4000 (10 lines) Telegrams: Selsomachi, London

THE 600 GROUP

554/SMT 158

ARCHDALE

HEAVY DUTY VERTICALS

for drilling up to 4" in steel!

This photograph, taken at the Lincoln Works of Ruston Bucyrus Ltd., shows their wise choice in selecting ARCHDALE for heavy duty vertical drilling machines. Built with a strength and rigidity to match the power required for continuous heavy work, these machines are available in 3 sizes. The 32" machine will drill up to 4" dia., in M.S., the 30" machine, 3" dia., and the 28" machine, 1½" dia. All three can be supplied with plain, elevating or compound tables.

We are exhibiting at the International Machine Tool Exhibition, London. June 22 — July 6. Grand Hall, Stand No. 40.

JAMES ARCHDALE & CO · LTD · LEDSAM STREET · BIRMINGHAM · 16

SOLE AGENT—ALFRED HERBERT LTD. COVENTRY

Grinding

THE PRECIMAX WAY AT FORD MOTOR COMPANY LTD

By courtesy of Ford Motor Company Ltd., Dagenham, we illustrate one of our PRECIMAX Model MPO machines set up for grinding the cones on two-speed intermediate gears. High rates of production are maintained to close limits, and the PRECIMAX ensures a consistently good finish.

The PRECIMAX range includes machines to improve performance on practically every precision grinding operation; plain and universal cylindrical grinders in a full range of sizes; fine grinding machines for ultra precision; surface grinders in reciprocating and rotating table types, etc.

Fine boring machines are also a speciality, and models are available with numbers of spindles to suit requirements, and fully tooled ready for immediate production

JOHN LUND LIMITED

CROSS HILLS, KEIGHLEY, YORKS.

Mechanical Tubing

Whether you require mechanical tubes of large or small diameter we can be of service to you, for we carry large and varied stocks of tubing of many sizes. These tubes are available in various finishes and lengths and are obtainable suitable for machining.

Write, 'phone or call for full particulars.

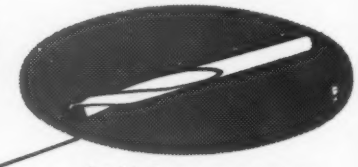
IMMEDIATE DELIVERY IN MOST CASES.

Markland Scowcroft LIMITED

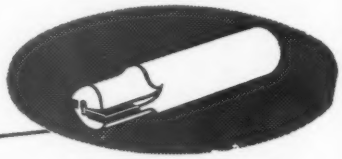
COX GREEN WORKS, BROMLEY CROSS, Nr. BOLTON

Telephone: EAGLEY 600 (5 lines) M.120

Twist Drills—for use on plastics and non-ferrous materials.



Special Cutters—router cutters supplied to customers' requirements.



Threading tools—illustrated is the external tangential type.

Keep down production costs

Because we manufacture every Centurion tool and EDIBRAC tip entirely at our Broadheath works, we are able to control completely their consistently high quality—and pass on savings in costs to the customer. EDIBRAC tungsten carbide has proved its worth in industry—there is a grade of Edibrac to cover every machining operation, and our technical staff is always ready to assist with your problems.

Think hard—think EDIBRAC!

CENTURION Tools Tipped with EDIBRAC

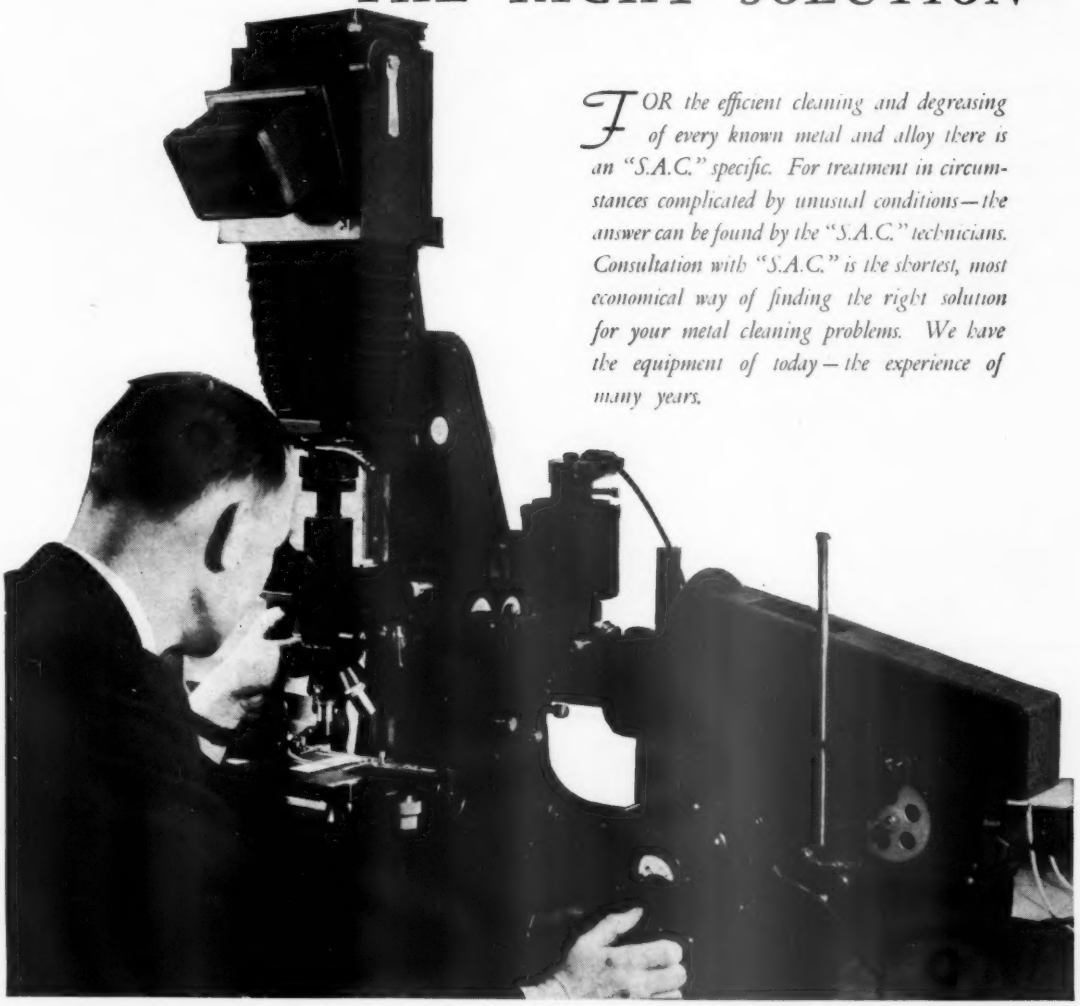
★ **We are exhibiting on Stand 642 at the International Machine Tool Exhibition, Olympia, London, June 22—July 6, 1956**

Free! Write today for a copy of the EDIBRAC Catalogue which lists the wide range and gives information on the use and maintenance of CENTURION Tools.

EDIBRAC LIMITED, CENTURION WORKS, BROADHEATH, Nr. MANCHESTER

dmEC10

In search of THE RIGHT SOLUTION



FOR the efficient cleaning and degreasing of every known metal and alloy there is an "S.A.C." specific. For treatment in circumstances complicated by unusual conditions—the answer can be found by the "S.A.C." technicians. Consultation with "S.A.C." is the shortest, most economical way of finding the right solution for your metal cleaning problems. We have the equipment of today—the experience of many years.

PRODUCTION PROVED PRODUCTS

SUNBEAM ANTI-CORROSIVES LTD.

CENTRAL WORKS · CENTRAL AVENUE · WEST MOLESEY · SURREY

Telephone: Molesey 4484 (5 lines) *Telegrams: Sunanticor, East Molesey*

Manufacturers of

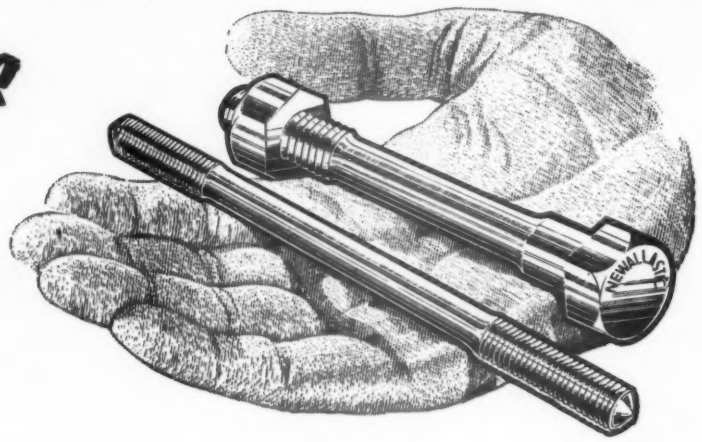
STRIPALENE · FERROCLENE · ALOCLENE · FERROMEDE · BRAZOCLENE

(Regd. Trade Marks)

APPROVED BY ADMIRALTY, WAR OFFICE AND AIR MINISTRY

Unique

"Newallastic" bolts and studs have qualities which are absolutely unique. They have been tested by every known device, and have been proved to be stronger and more resistant to fatigue than bolts or studs made by the usual method



C. P. Newall & Co., Ltd.

POSSILPARK GLASGOW · N

PATENT CALIPER GAUGE MODEL 52

Each month one of the seven main advantages of this fine precision instrument will be described.

- Many different gauging positions can be obtained.
- The anvils are set so that they do not roll.
- ★ All shearing action is eliminated.
- Particularly suitable for gauging shouldered work.
- Can be used for either left or right hand threads.
- Particularly suitable for the gauging of acme forms of thread.
- Can be supplied for "GO" only, or "NOT GO" only, or both "GO" & "NOT GO" combined.

NOTE THIS MONTH'S IMPORTANT FEATURE

★ **ALL SHEARING ACTION IS ELIMINATED**

As the anvils are radial all shearing action is eliminated. This is a particularly advantageous feature, especially when soft metals are being gauged.

Write today for a descriptive leaflet to:-

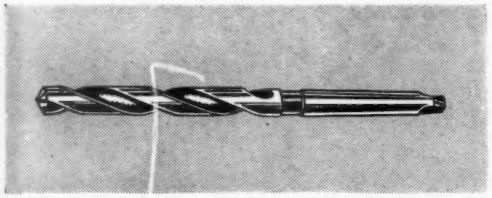
HORSTMANN

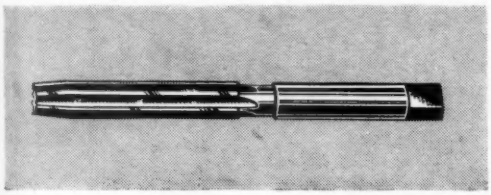
THE HORSTMANN GEAR CO. LTD., NEWBRIDGE WORKS. BATH. ENGLAND.

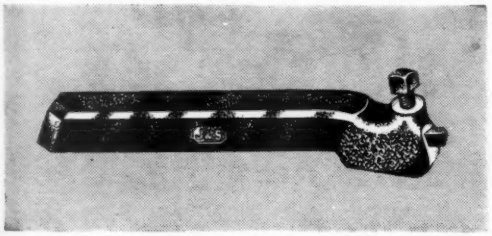
TEL: BATH 7241 · GRAMS: HORSTMANN BATH

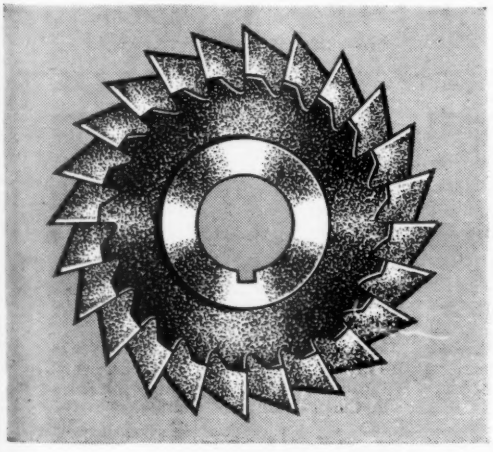
Engineers' Small Tools and Accessories

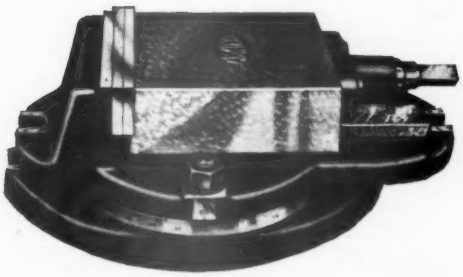
TWW

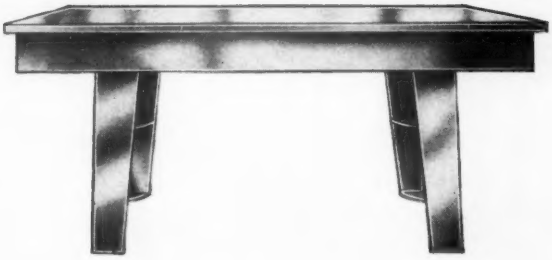


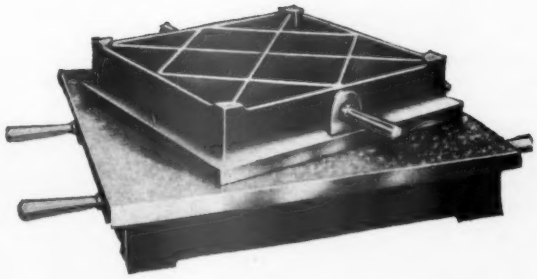












'Wards might have it' applies to Small Tools and Accessories as it does to all the branches of industry served by Wards. A complete and dependable range is available from stock or very early delivery.

THOS. W. WARD LTD · ALBION WORKS · SHEFFIELD · Tel. 26311 (22 lines)

LONDON OFFICE · BRETTENHAM HOUSE · LANCASTER PLACE · STRAND · W.C.2

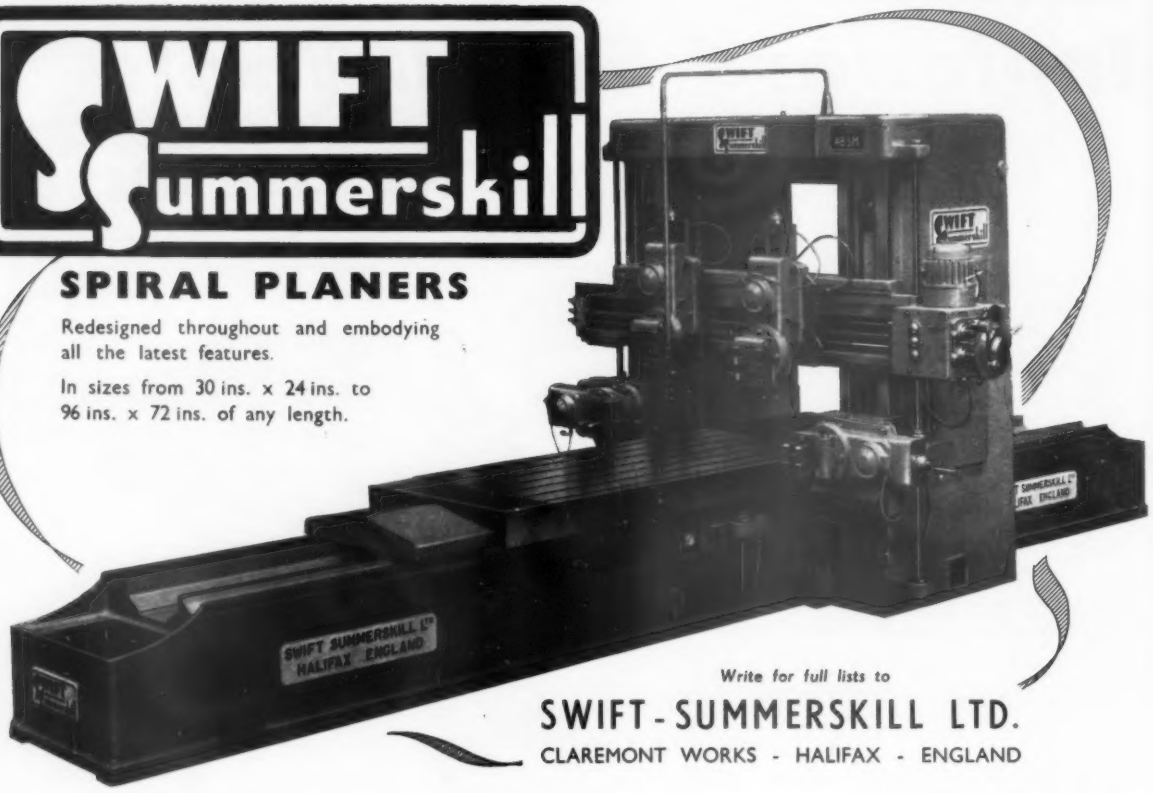
EST. 2

SWIFT Summerskill

SPIRAL PLANERS

Redesigned throughout and embodying all the latest features.

In sizes from 30 ins. x 24 ins. to 96 ins. x 72 ins. of any length.



Write for full lists to

SWIFT-SUMMERSKILL LTD.

CLAREMONT WORKS - HALIFAX - ENGLAND

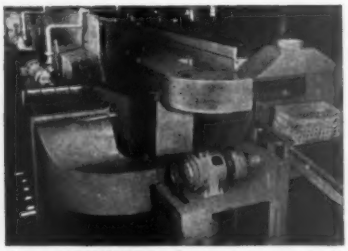
Bratby

HERE ARE THREE EXAMPLES

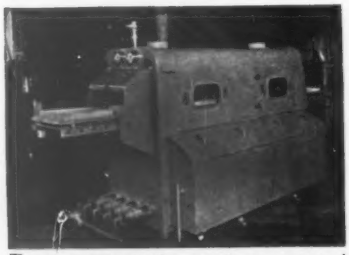
INDUSTRIAL CLEANING MACHINES

can be designed to meet your particular cleaning problems

This illustration shows a machine cleaning crank cases in the production line. It is equally capable of cleaning small parts in baskets.



A power driven conveyor system is employed with this cleaning machine for ball bearings.



Trays carrying the work are pushed through on a roller conveyor by hand in this cleaning installation.

Whilst offering a very wide variety of standard cleaning equipment, it is BRATBY policy, wherever possible to design the machine to meet the particular cleaning problem. Careful study of each individual problem ensures maximum efficiency and economy of the plant in operation. The illustrations show but a few of the specific types of Cleaning Machines designed by BRATBY for individual needs.

Designed and Manufactured by:

BRATBY & HINCHLIFFE LTD · GORTON LANE · MANCHESTER 18 · Tel.: EAST 2435

This illustration shows an Arrow 30 amp Contactor actual size.

The smallest panel-mounting contactor on the market

50% saving in weight and size.

Complies with B.S.S. 775 for breaking capacity.

Coils and contacts changed in a matter of seconds.

Exceptionally low wattage consumption. C.S.A. approved.

Conforms with American N.E.M.A. specification.

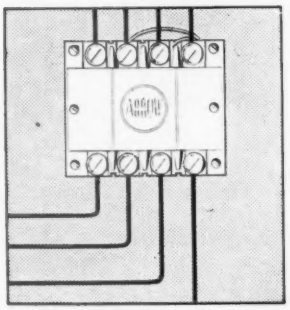
Comprehensive spares facilities in U.S.A. and Canada.

Three sizes — 30, 50 and 100 amps. at 550 volts A/C rating.

D/C ratings on request.

STRAIGHT-THROUGH WIRING

This is a completely new, built-in, advanced wiring design. Installation time is greatly reduced and circuit identification is easy and positive.



SEND FOR NEW CATALOGUE MS.9

ARROW ELECTRIC SWITCHES LTD · HANGER LANE · LONDON · W.5

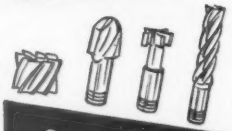
It's DELIVERY BY RETURN

WITH ALL CLARKSON MILLING CHUCKS AND CUTTERS

MANCHESTER
98 OXFORD ROAD, 13
Telephone Ardwick 4804

LONDON
124 HAMMERSMITH ROAD
W.6
Telephone Riverside 8241

BRISTOL
17 CUMBERLAND STREET
2



GLASGOW
430 CROWN STREET, C.5.
Telephone South 1942

It's no slogan—it's a fact. Simply lodge your orders with Clarksons. Teams of technicians—all working like beavers—specialists in milling techniques, based on these amply stocked depots, have built up an unrivalled technical service demonstrating and advising customers. Most of the Orders received in the morning are on their way by mid-day, and all orders for standard items are despatched the same day. This is the routine at all branch offices as well as at Nuneaton.

BIRMINGHAM
15 HEATH MILL LANE, 9
Telephone Victoria 3994

AT YOUR SERVICE

Clarkson
(ENGINEERS) LTD.

NUNEATON · WARWICKSHIRE

Cheapest in the Long Run

Fitted in minutes without dismantling machinery. Stocks of belting can be reduced by 90%. Five coils of "BRAMMER" will replace 295 standard sizes of solid endless ropes.

Tested, pre-stretched and matched belts available from stock.

Coloured studs identify "BRAMMER" 40° angle sizes.

The original and only rubber V-link belt which has been tested and proved for over 25 years.

V-Link FLEXIBLE NON-SLIP TRADE MARK BRAMMER BELTING ENDLESS *belting*

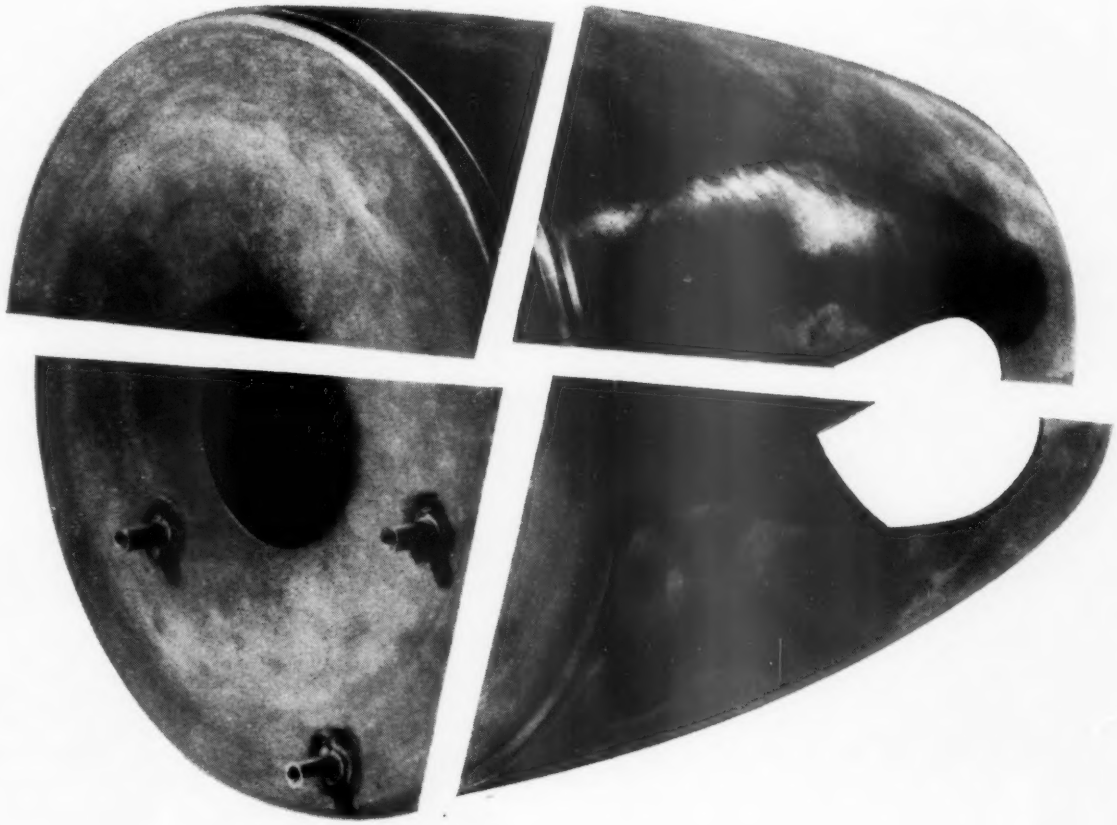
H. BRAMMER & CO. LTD. HUDSON RD. LEEDS 9

E.4

Give you three guesses

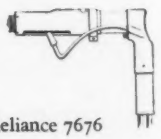
THIS IS:—

(A) ***Part of a vacuum cleaner*** **(B)** ***A coffee percolator*** **(C)** ***An artificial satellite***



The correct answer is B. This picture at least shows plainly one of the great advantages to be gained by Crompton Parkinson Stud Welding. The coffee percolator is an example of re-designing with stud welding specifically in view. The three brass bosses which secure the electrical mechanism to the percolator are cleanly welded on to the base and there is no perforation of the metal or risk of subsequent leakage. In many branches of light and heavy industry Crompton Parkinson Stud Welding is helping to speed production and improve design. Let us give you a demonstration on your own premises and show you how simple and inexpensive it is.

THE STUD WELDING ORGANISATION



ELECTRICAL EQUIPMENT

Crompton Parkinson LIMITED 1-3 Brixton Road, London, S.W.9. Telephone: Reliance 7676

Specialists in

Rust Preventive Oils & Coatings

based on Lanolin

Organic Finishes Division

Croda Ltd

Goole
London
New York
Milan
Manchester
Bradford

Croda House, Snaith, Goole, Yorks. *Tel : Snaith* 277

plug in where you will

An entirely new system of power distribution, the EMS "Miniplug" allows any number of light fittings, office machines and small tools to be "plugged-in" anywhere along an overhead duct. The system is safe and economical—"plugging-in" takes only a few seconds—and there is no waste of conduit or cable. "Miniplug" ducting is supplied in 8 ft. lengths, is simple to install, and can be modified or extended at will.

MINIPLUG
distribution
duct

E.M.S. ELECTRICAL PRODUCTS LTD

28-32 THE BUTTS COVENTRY Tel: COVENTRY 61091-2-3 Grams: DISPATCH COVENTRY

P1629

To keep production moving . . . fast !

This No. 10 has been arranged for double indexing

The Verticalauto performs a whole chain of operations for a single load-and-unload.

Precious time is lost when components in production are transferred from one machine to another. If rates of output vary, unfinished components pile up at one machine while another lies idle. . .
The versatility and scope of the big, electro-hydraulic Verticalauto No. 10 are such that many kinds of components can be machined from rough to finish on the one machine.
How much time and money this can save we'll be pleased to show you—with a production estimate on a job from **your** plant.

SEE THE NO. 10 AND OTHER RYDER PRODUCTS ON STAND 16 AT THE FORTHCOMING INTERNATIONAL MACHINE TOOL EXHIBITION AT OLYMPIA, LONDON.

Ryder **VERTICALAUTO**

THOS. RYDER AND SON LIMITED, TURNER BRIDGE WORKS, BOLTON, ENGLAND

Makers also of SINGLE SPINDLE RYDERMATICS and PISTON RING LATHES

Head and shaft above the others

The material and craftsmanship of these hammers and all Bedford tools makes them stand out. They are made from the finest Sheffield steel and are sold with or without selected ash or hickory handles.

if it's a good hammer it's a

BEDFORD

JOHN BEDFORD & SONS LTD. LION WORKS, SHEFFIELD

715

Faster & far easier screw thread repair..

..keeps them in production!

HELI-COIL*

*REGD. TRADE MARK

SCREW THREAD INSERTS

ARE ESSENTIAL TO MODERN MACHINE MAINTENANCE

In every branch of industry; for every machine running, HELI-COIL is available to reduce production time lost through screw thread failure. Further, the result is a strip proof, non-corrosive, stronger, harder wearing thread than the original.

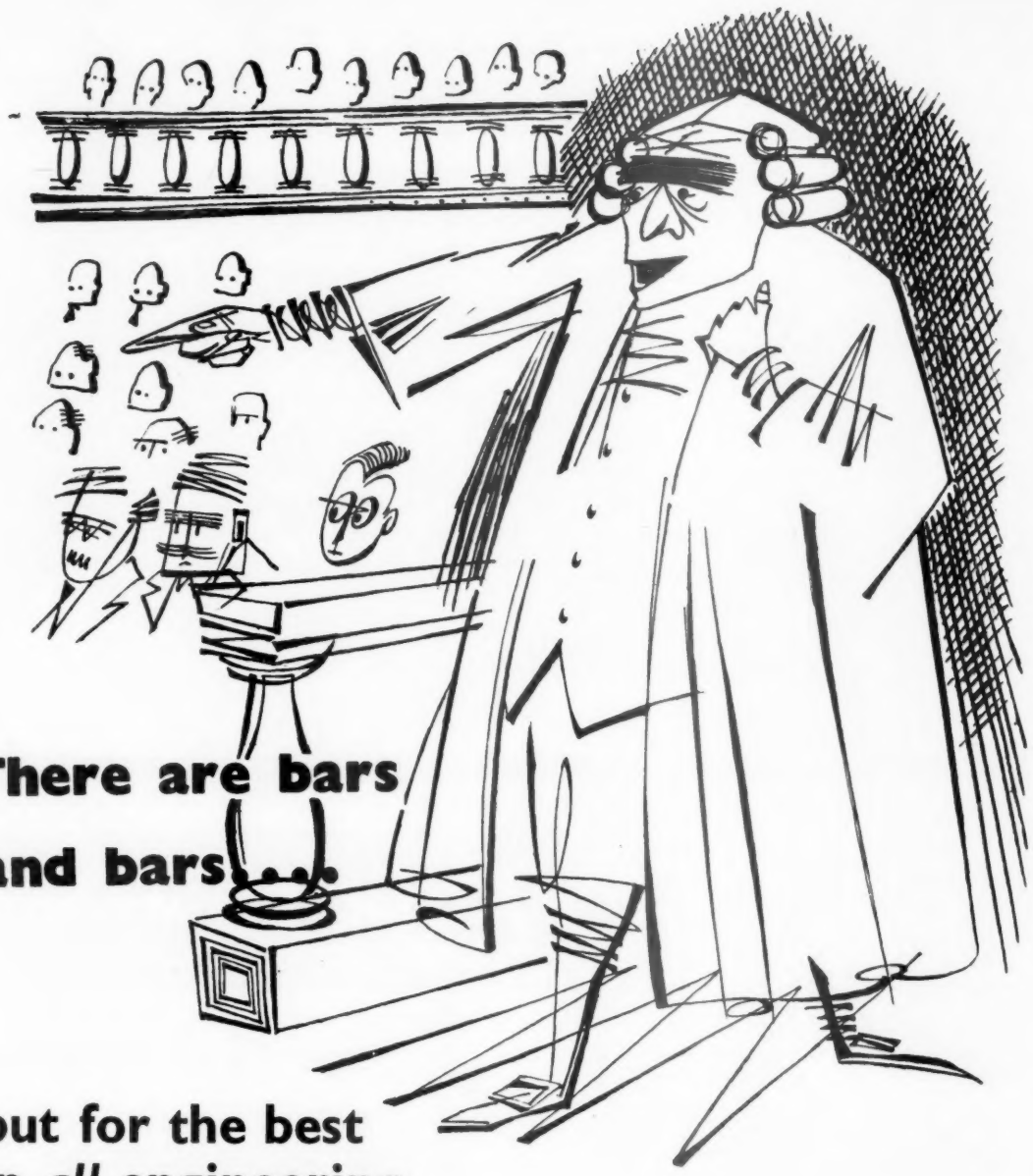
A few minutes straightforward work with the contents of this kit and your machine is running again.

Order To-day From...

FYFE & McGROUTHER LTD., GLASGOW, C.4.
WHITE MILNE & CO., DUNDEE.
HENRY OSBORN LTD., NEWCASTLE-ON-TYNE.
THOMAS SMITH & CO., HALIFAX.
ALEXANDER KENYON & CO. LTD., MANCHESTER 3.
G. F. BRIDGES LTD., BIRMINGHAM, 4.
WOODBERRY CHILLCOTT & CO. LTD., BRISTOL.
MODERN TOOL & EQUIPMENT CO. LTD., BELFAST.
SMITH & GRACE (SALES) LTD., LONDON, N.W.1.

ARMSTRONG PATENTS CO. LTD. BEVERLEY, YORKSHIRE

PIA/4



There are bars and bars...

but for the best in *all* engineering uses there are Kirkstall Bright Steel Bars

Kirkstall Forge
Engineering Limited

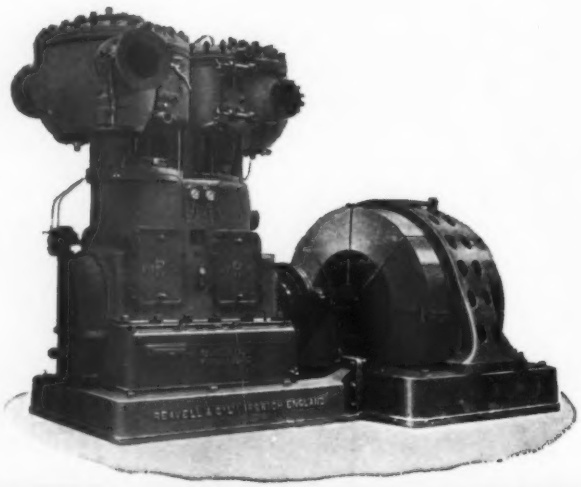
LEEDS 5, YORKSHIRE · TELEPHONE: HORSFORTH 2821

WHEN YOU ARE WANTING NEW

AIR COMPRESSORS

DO NOT FORGET THAT WE HAVE

A COMPLETE RANGE TO SUIT ALL DUTIES



Whatever it is you need—large or small capacity—high or low pressure—we can supply the best machine for the purpose, and our fifty years of specialised experience are at your service.

REAVELL & CO. LTD.

IPSWICH

Telegrams: Reavell, Ipswich Telephone Nos.: 2124-5

Tapping ?

'ARCHER' TAPPING ATTACHMENTS

WITH *AUTOMATIC* REVERSE

4 special features

- SIMPLE TO OPERATE
- TAKES STANDARD HAND TAPS
- FITTED WITH SAFETY FRICTION DRIVE
- HARDENED NICKEL CHROME STEEL GEARS

'ARCHER' Tapping Chucks are also made as separate units for tapping operations where the auto-reverse is not required, and can be supplied with friction drive having the Morse Taper Shank integral with the friction box; or with positive drive having Jacobs No. 2 series taper bore.

Ask for List No. 105

STAND No. 304 International Machine Tool Exhibition, London, 22nd June—6th July, 1956.

FRANK GUYLEE & SON LTD

ARCHER TOOL WORKS · MILLHOUSES · SHEFFIELD 8

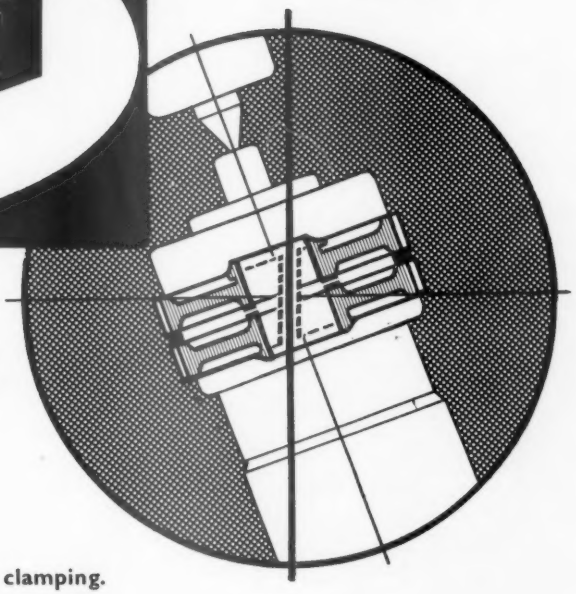
Hydrax production data

Patent No. 708767
(Foreign Patents Pending)

HELICAL GEARS

60 TEETH. 8·5 D.P.
20° HELIX ANGLE. 1½" FACE WIDTH
7·500 PITCH CIRCLE DIA.
MAT. 1 PER CENT CHROMIUM STEEL STAMPING 45/55 TONS TENSILE APPROX.

CUT TWO PER SETTING. USING THREE START HOB. FINISH SUITABLE FOR SUBSEQUENT GRINDING OR SHAVING OPERATIONS.
HYDRAX FLOOR TO FLOOR TIME PER GEAR 2·25 MINS.



With its tremendous production rate, the Hydrax is the ideal gear hobbing machine for any Automation plant layout. Its output and accuracy slash the cost of both gear cutting and subsequent operations.

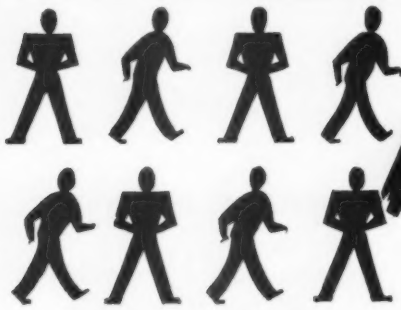
HYDRAX FEATURES INCLUDE:-

- **Hydraulically operated quick acting work clamping.**
- **Automatic cutting cycle under control of one push button.**
- **Reduced hob travel for helicals.**
- **Automatic hob shift.**
- **No differential or lead cam.**
- **Automatic loading.**

Please write for publication ***M.104.2.***

Hydrax

THE
DAVID BROWN
CORPORATION (SALES) LIMITED
MACHINE TOOL DIVISION
BRITANNIA WORKS SHERBORNE STREET
MANCHESTER 3



MAN POWER

Time on the job enters into every stage of industrial production. Arrivals and departures, time on the bench or machine, breaks for meals and overtime are all related to cost of production.

GLEDHILL-BROOK Time Recorders provide the most adaptable means of recording regular or irregular hours on the job, automatically and accurately, every minute of every hour day and night.

Available with either 8-day mechanical clock movement or electrical operation.

IS TIME POWER

Write for full information and illustrated leaflet to:—

GLEDHILL - BROOK TIME RECORDERS LIMITED

20, EMPIRE WORKS, HUDDERSFIELD.

It must be...

Durachrome treatment gives a surface of exceptional hardness (910/930 Vickers Diamond) which resists abrasion and corrosion. Cylinders, shafts, rams and all heavy duty components have a greatly increased life by Durachrome application of hard chromium. One part or production quantities can be treated.

Estimates and full particulars from

DURACHROME LTD

171-177, ILDERTON RD., LONDON, S.E.16.

Telephone: **BERMONDSEY 2883-2884**

HARD CHROMIUM SPECIALISTS

... it IS Durachrome!

(REGISTERED TRADE MARK)

continuous COPPER BRAZING FURNACES with REMOVABLE elements

Birlec Limited can now offer continuous copper brazing furnaces with removable non-metallic elements as standard equipment. Extensive production trials have taken place and the following advantages proved:—

- ★ ***Element replacement is easy and can take place, if necessary, while the furnace is in operation.***
- ★ ***Element replacement does not involve rebricking, and expensive downtime is thus reduced.***
- ★ ***Element life is no shorter than with conventional nickel-chromium resistors.***

...also INDUCTION HEATING

For brazing a small part to a large article, induction heating equipment is the answer; localised heat means no wasted heat and a "machine tool" approach to equipment design makes the process ideal for quantity-production methods.

Illustration left: A standard 5kW unit, for brazing carbide tool tips; Photograph by courtesy of EDIBRAC LTD., Broadheath, Cheshire, manufacturers of Tungsten Carbide products.

Designs are completed for standard 6", 8" and 12" furnaces; may we send details? We should also be pleased to arrange a visit to our Heat Treatment Division, near the main works in Tyburn Road, where test pieces can be brazed in a furnace of this type.

BIRLEC LIMITED

ERDINGTON · BIRMINGHAM · 24

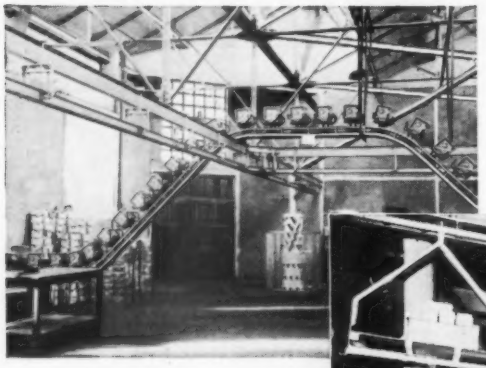
BIRLEC

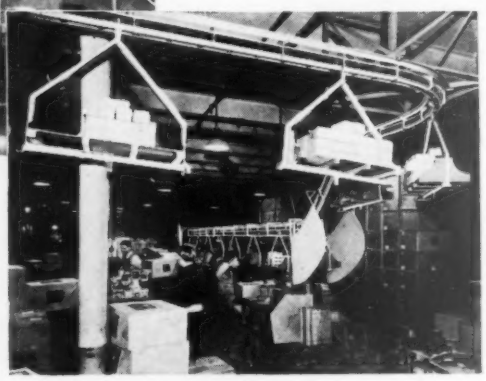
Sales and service offices in **LONDON · SHEFFIELD · GLASGOW · NEWCASTLE-ON-TYNE**

SM/B.2134.54

(Member of the A.E.I. Group of Companies)

DUAL-DIRECTIONAL CONVEYOR SYSTEMS





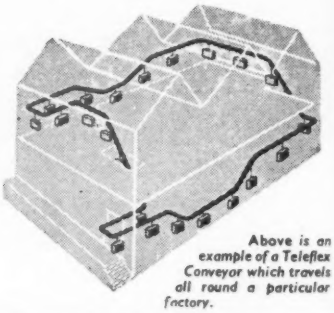
Above: *The Teleflex dual-directional chain Conveyor adapted to carry tins of biscuits.*

Right: *Overhead chain conveyor carrying cigarettes in packing and despatch departments at the factory of Messrs. W. A. & A. C. Churchman.*

Now thoroughly proved in service with some of the most well-known manufacturers the Teleflex Dual-directional Chain Conveyor can be supplied soon after receipt of your order. The design is simple, efficient, well proportioned and perfectly balanced.

Teleflex Conveyor systems are constructed from standardised units which are capable of being formed into individual systems to suit any particular factory or production layout.

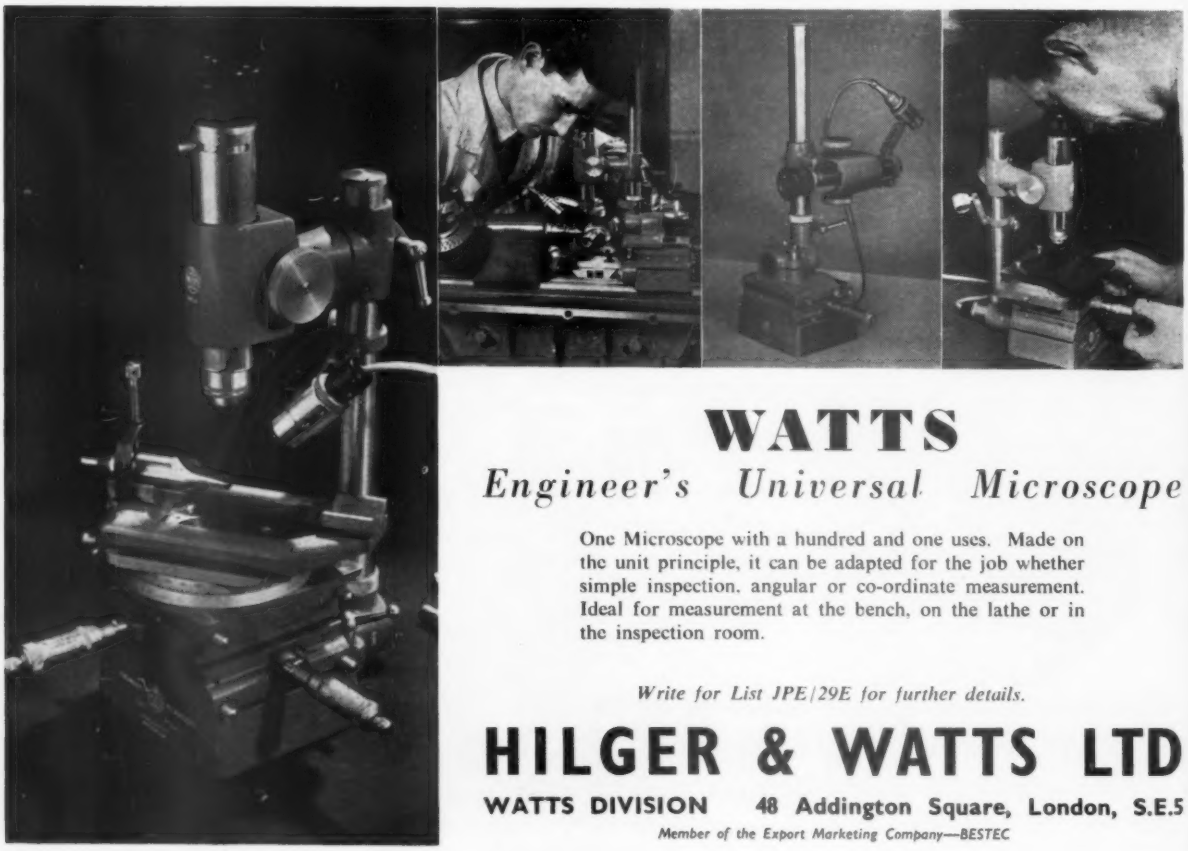
Write for illustrated brochures: Cable Conveyors ref: Con. I.P.E. and Chain Conveyors ref: Con. 2 I.P.E.



Above *is an example of a Teleflex Conveyor which travels all round a particular factory.*

TELEFLEX PRODUCTS LTD

Chadwell Heath, Essex Telephone: SEVen Kings 5771 (7 lines)



WATTS

Engineer's Universal Microscope

One Microscope with a hundred and one uses. Made on the unit principle, it can be adapted for the job whether simple inspection, angular or co-ordinate measurement. Ideal for measurement at the bench, on the lathe or in the inspection room.

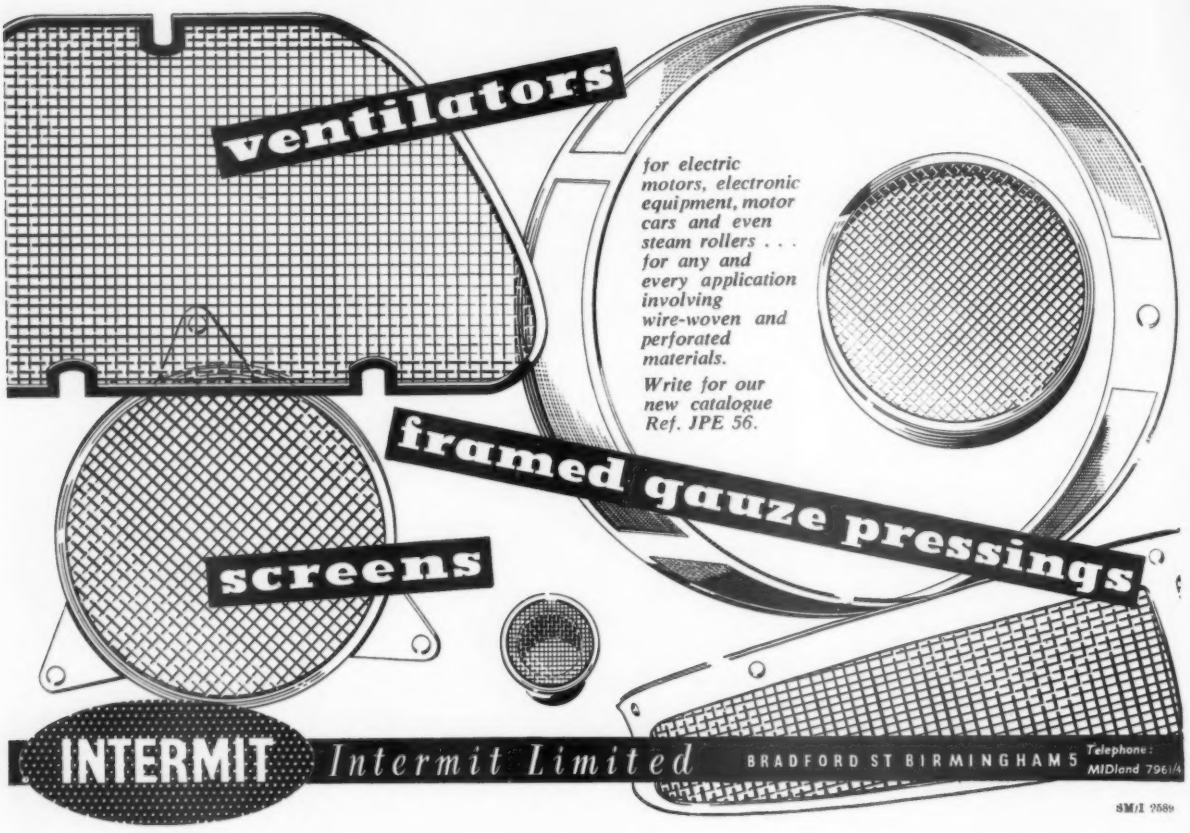
Write for List JPE/29E for further details.

HILGER & WATTS LTD

WATTS DIVISION 48 Addington Square, London, S.E.5

Member of the Export Marketing Company—BESTEC

Hard and fast
the story of
Cutanit
tips and tools
NO. 1 IN A SERIES: EXTENSIVE RESOURCES FOR RESEARCH
Behind the constant scientific control of the quality of Cutanit lies the combined efforts of the Research and Developments Organisation of Jessop-Saville, Metropolitan-Vickers Electrical Co. Ltd., and B.S.A. Co. These continual efforts have one object in view—improved precision cutting over long periods. For consistency throughout the materials and a high performance on all types of materials—steels, alloys, cast iron, glass, plastics, rock and concrete, etc.—there is no equal anywhere.
WM JESSOP & SONS LTD
BRIGHTSIDE WORKS SHEFFIELD
J J SAVILLE & CO LTD
TRIUMPH WORKS SHEFFIELD


ventilators
for electric motors, electronic equipment, motor cars and even steam rollers . . . for any and every application involving wire-woven and perforated materials.
Write for our new catalogue Ref. JPE 56.
framed gauze pressings
screens
INTERMIT
Intermit Limited
BRADFORD ST BIRMINGHAM 5
Telephone: MIDland 7961/4
SM/I 2589

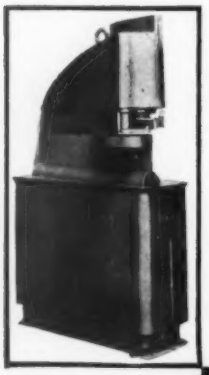
POWER APPLICATION

at its best

RELIABILITY AND SERVICE

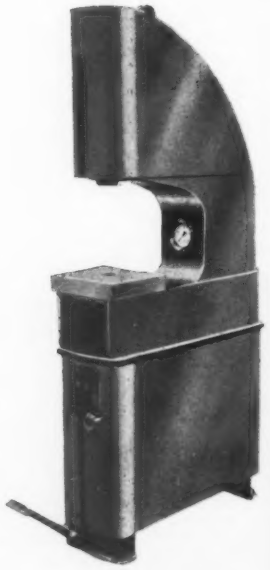
HYDRAULIC POWER PRESS

- Occupies only 3 sq. ft.
- Weighs only 10 cwt.
- Develops up to 12 tons pressure
- Compact and Sturdy Build
- Operators hands free at all times
- Extreme sensitivity of Ram Control
- Foot Control



HYDRAULIC CROPPING MACHINE

- Weighs only 5 cwt.
- Up to 17 tons pressure on the Shear Blade
- Fully Automatic Operation and Foot Control
- Cutting speed up to 34 cuts per minute
- Grip on metal to be cut up to 1½ tons
- Mild steel bar up to 4" x ¼" cut at one stroke
- Negligible burr on cut metal



PILOT

PILOT WORKS LIMITED (INCORPORATING M. EDWARDS AND SONS) MANCHESTER ROAD BOLTON
TELEPHONE BOLTON 5545/6/7 TELEGRAMS TIPGEAR BOLTON LONDON OFFICE 3 SOUTHAMPTON PLACE WC1 TELEPHONE CHANCERY 5130
P1054

For Heavy Duty *Continuous* Grinding

- RIGID CONSTRUCTION
- UNFAILING RELIABILITY
- FREE FROM VIBRATION
- PROVISION FOR EFFICIENT DUST EXTRACTION
- MADE IN THREE SIZES

The **UNION**

MOTOR-DRIVEN GRINDING MACHINES

Illustrated literature of Union Motorised Grinding and Polishing Machines is free on request.

T. S. HARRISON & SONS LTD., HECKMONDWIKE, YORKS.

As vital as a blood transfusion....

This is true of any modern tool where oil is the hydraulic medium. Two things are demanded — sump replenishment as required and renewal at fixed intervals — using only the correct oil and grade. The VETA grades are produced specifically for this exacting duty and you can always rely on them. The latest edition of "Machine Tool Lubrication" contains much data germane to this important subject. Ask for a copy on your business heading.

FLETCHER MILLER

Machine Tool Lubricants

VETA - for hydraulic systems generally
GENA - the machine tool lubricant
ALMARINE - for all grease points

See our exhibit on Stand D510 at the B.I.F.

FLETCHER MILLER LTD · ALMA MILLS · HYDE · CHESHIRE

MTL31

More and more firms machining non-ferrous components are endorsing the amazing high production capabilities of Wadkin Radial Arm Routers. Production times which were previously calculated in hours have in some instances been reduced to minutes! In addition, this Wadkin, by employing cutting speeds up to 18,000 r.p.m. ensures a remarkably free cutting action and an exceptionally smooth finish. The only way to appreciate the enormous possibilities of this machine is to see it in operation. May we arrange a demonstration preferably on your own components?

Machining aircraft components in light alloy
Photograph by courtesy of Messrs. Morfax Ltd., Mitcham.

This Wadkin Heavy Duty Radial Arm Router type L.Y.R. will machine practically all the aluminium light alloys in cast, forged or rolled forms, also brass, zinc, certain coppers and lead, and it is also suitable for many plastic materials.

Revolutionising machining times on NON-FERROUS METALS

Wadkin

Wadkin Ltd., Green Lane Works, Leicester. Telephone: Leicester 67114

London Office: 62-64 Brook Street, W.1. Telephone: MAYfair 7048-9

simplify

Lang Pneumatic Control Equipment is the simple answer where operational sequences using all forms of machinery are involved. Compact, simple to operate, it brings more functions within the reach of a single operator; enables greater use of semi-skilled labour; and eliminates the human error which so often accompanies independently controlled sequences. There is hardly a precision tool or function in industry to which it cannot be applied. With its simplicity, ability to withstand heavy continuous operation and its multi-purpose based on standard components, Lang Pneumatic is the product of many years active collaboration with Production Engineers. Lang Pneumatic Control Gear is entirely non-corrodible and every part is made from stainless steel or non-ferrous metals. Over 700 major industrial concerns in this country alone employ Lang Pneumatic Control Gear.

Production of this clevis pin under Lang control was doubled with half the labour used on manual operation of machinery.

LANG PNEUMATIC CONTROL EQUIPMENT

entirely non-corrodible

Plan with

LANG PNEUMATIC LTD

VICTORY WORKS BIRMINGHAM ROAD WOLVERHAMPTON Tel: 25221-2-3

1587

STORAGE
SPRAY
JACKETED
CHEMICAL
MIXING
HEATER
LEAK TEST
COOLER
REACTION
LINEN
SEPARATOR
HYDRO
ROAD WAGON
CONDENSE
OIL
ACID
FUEL

TANKS and VESSELS

of all types for all purposes

We offer an unequalled service in the design and fabrication of this highly specialised class of equipment. If you have any problem involving bulk storage, handling, conveyance or processing of liquids at normal or maintained temperatures, it is possible that we could save you considerable worry, much time and money.

PRESSURE
VACUUM
FILTER
MIXING
REACTION
ACID
JACKETED

HELMSMAN PRODUCTS

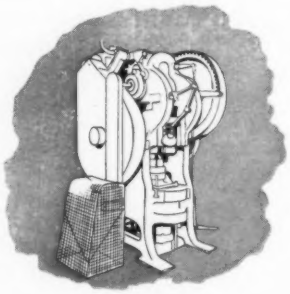
W·B·BAWN & COMPANY LIMITED

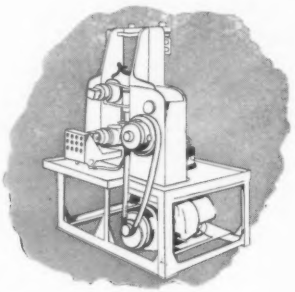
BYRON WORKS, BLACKHORSE LANE
LONDON, E.17 · LARkswood 4411/4

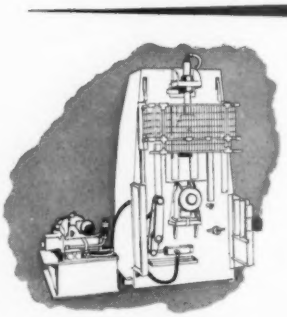
IT PAYS TO COME TO BAWN'S FIRST!

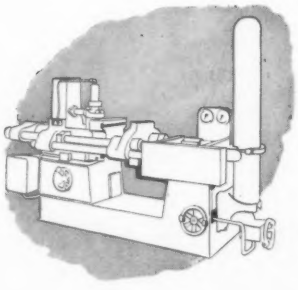
All kinds of
SPECIAL PURPOSE MACHINERY

We at Sheepbridge Equipment Limited have a wide experience of manufacturing most types of machinery. Our facilities for manufacturing machines to rigid specification are second to none. No job is too large or too difficult for us to tackle. Let us quote for your requirements for precision built machines.









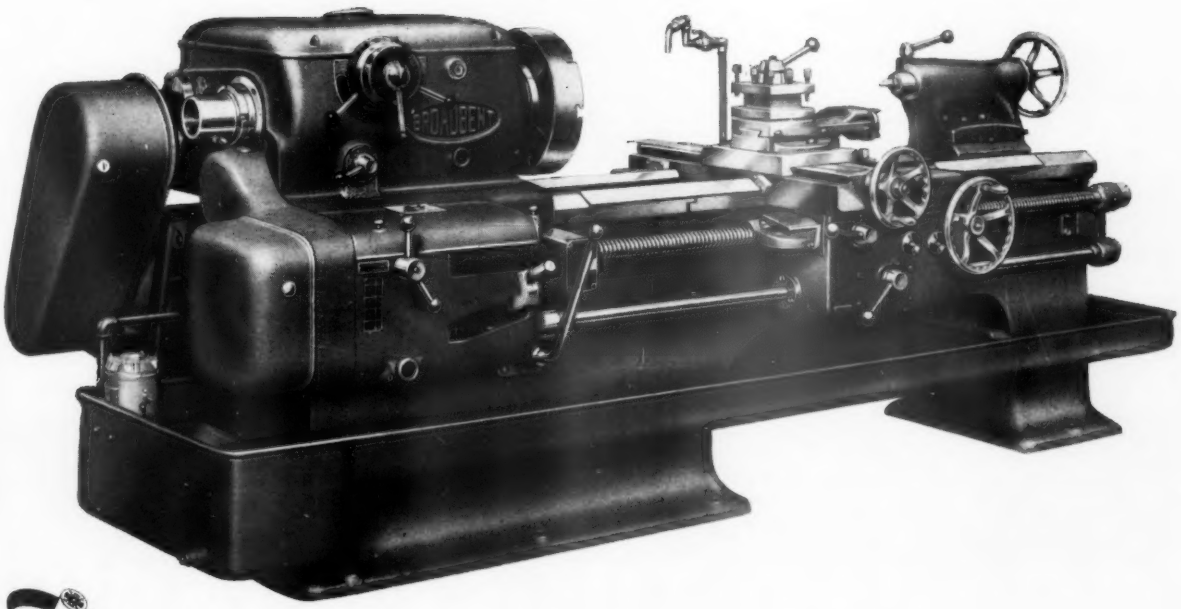
SHEEPBRIDGE EQUIPMENT LIMITED

(*One of the Sheepbridge Engineering Group*)

CHESTERFIELD ENGLAND

OA/3330

BROADBENT *Lathes*



See us at the
International Machine Tool
Exhibition
Olympia
Stands 36 & 504

For more than 80 years the name of BROADBENT has been synonymous with high quality centre lathes. The accumulated knowledge and experience of lathe manufacture gained during that time is reflected in the design and performance of present-day machines.

In addition to standard Centre Lathes from 8½" to 24" height of centres, we also specialise in Surfacing and Boring Lathes, Break Lathes, Heavy Duty Horizontal Plano-Milling Machines and Vertical Boring and Turning Mills.

Please write for descriptive literature illustrating the full range of Broadbent Machines.

BROADBENT

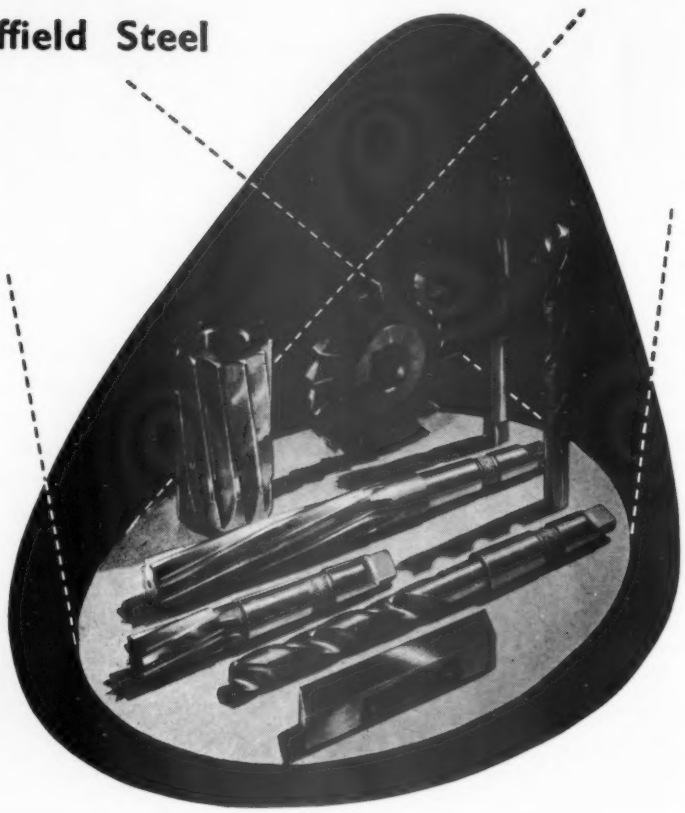
HENRY BROADBENT LIMITED

SOWERBY BRIDGE, YORKS *Telephone :* HALIFAX 81331

BL3

Three Centuries of Sheffield Steel

Here is a selection from the wide range of MARSH CYC High Speed and MARSH Carbon Steel Engineers' Tools. These tools, with MARSH Steels and Wire, are used by Government Departments and firms with household names, at home and abroad. We are a family firm, founded in 1631, and have a proud tradition of personal service to our customers the world over. MAY WE HELP YOU ?



MARSH BROTHERS

of Sheffield England

Galtona TRADE MARK

GROUND THREAD TAPS

These taps are made to very close tolerance, and are ground from the solid, thus eliminating the risk of distortion. Both standard and special taps can be supplied either in H.S.S. or alloy steel.

Write for illustrated catalogue.

Richard Lloyd Limited

STEELHOUSE WORKS · OLIVER STREET · BIRMINGHAM 7

Telephone Aston Cross 3001 (4 lines) Telegrams "Cogs, Birmingham"

NORTHERN AREA OFFICE: A. V. Green, Britannia House, Wellington Street, Leeds

LONDON AREA OFFICE: A. J. Percy, 240, Romford Road, Forest Gate, London, E.7.

CEJ

MIKROKATOR No. 500

A new smaller edition of the famous MIKROKATOR

Incorporates the same frictionless "twisted-strip" amplification, but designed for all applications where dial gauges would be used.

MIKROKATOR No. 548

This shows the new Mikrokator adapted for bore measurements by means of interchangeable measuring heads covering diameters from .125" to 1.00".

CEJ PRODUCTS

Ground Thread Taps
Screw Plug Gauges
Screw Ring Gauges
Circular Chasers and Holders
Round Dies
Thread Milling Hobs
Thread Rolling Dies
Plain Plug Gauges
Micro Snap Gauges
Surface Finish Indicators
Micrometers
Bore Gauges
Deltameters (Automatic Sizers)
Drill Chucks
Gauge Blocks
Dynamometers
Extensometers
Plain and Screw Snap Gauges
Plain Ring Gauges
Gronkvist Drill Chucks
Metron Dial Gauges
Tapping Attachments
Multiple Interference Microscopes

C.E. JOHANSSON LTD.

PRECISION TOOLS AND INSTRUMENTS

A.I.D. AND A.P.I. APPROVED

SOUTHFIELDS ROAD, DUNSTABLE, BEDS · TEL: DUNSTABLE 422/3

DH8/2364

Ransomes Forklifts are available in sizes from 10 cwts. to 2 tons and with many types of attachment for handling all forms of load. **Ask for Forklift Catalogue.**

Ransomes FORKLIFT TRUCKS

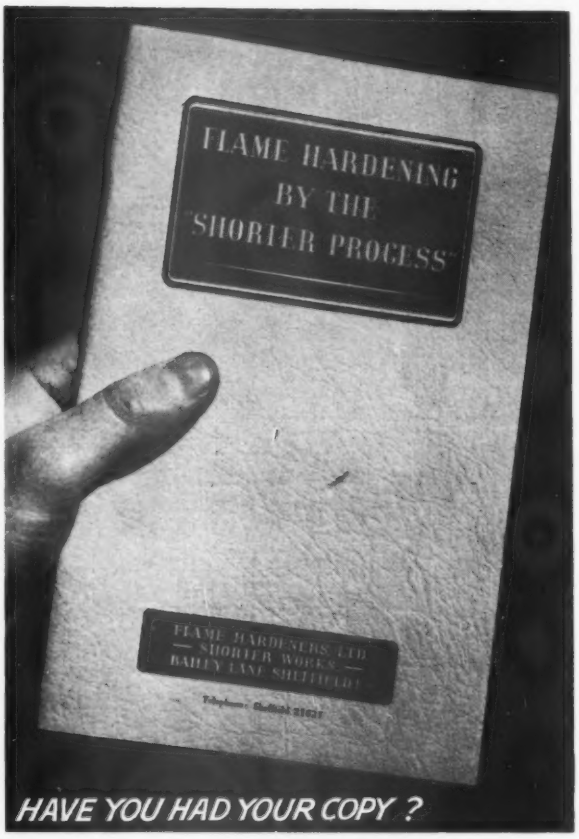
THE FIRST NAME IN TRUCKS

Ransomes

Ransomes platform Trucks are available in many sizes, with or without elevating platforms. Send us your problem. **Ask for Electric Platform Truck and Tractor Catalogue.**

Ransomes ELECTRIC PLATFORM TRUCKS AND TRACTORS

RANSOMES SIMS & JEFFERIES LTD.
ORWELL WORKS, IPSWICH
Telephone: IPSWICH 2201



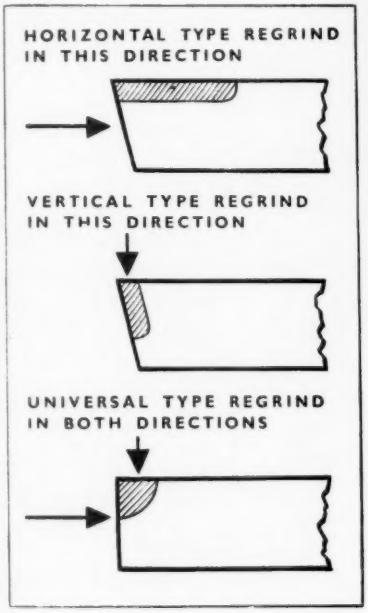
HAVE YOU HAD YOUR COPY ?

GUARDS *that are different*

Pinder Mild Steel Guards are designed to enhance the lines of your Machine Tools. They combine many advantages - strong: neat appearance: easy installation: no machining.

Improve your Machine Tools with a Pinder Guard

W. PINDER & SON LTD PETERBOROUGH


HORIZONTAL TYPE REGRIND IN THIS DIRECTION
VERTICAL TYPE REGRIND IN THIS DIRECTION
UNIVERSAL TYPE REGRIND IN BOTH DIRECTIONS

Which method of regrinding?

When it comes to designing many special tools, how you regrind them is what matters. Horizontally, vertically, or a combination of both? It's quite simple for us, using the Stag Athyweld patent deposit welding process, to build up tools suitable for any of these three main methods. Whichever method you adopt, you get just enough metal for your purpose. No paying for costly metal that won't be used, but design is all important. Let our technicians help to design your tools correctly for welding, and let us send you our Publication 66B which shows some applications of the process. Use the request form now.

STAG ATHYWELD

To Edgar Allen & Co. Ltd., Sheffield, 9.
Please post "Publication 66B" to:
Name.....
Firm.....
Address.....
.....*I.P.E.*

EDGAR ALLEN & CO.,LTD.
IMPERIAL STEEL WORKS · SHEFFIELD · 9
PHONE: SHEFFIELD 41054 GRAMS: ALLEN SHEFFIELD 9

it's all very well but...

When a piece worker starts on "ifs" and "buts" about press guards, it is time you asked UDAL about the famous 'Fastrip' Synchronised Guards for **increased** production and **increased** safety. The 'Fastrip' is worked by compressed air and guard and clutch are synchronised to ensure split-second timing. Send for full details today.

J. P. UDAL Ltd

INTERLOCK WORKS, COURT ROAD, BIRMINGHAM, 12.

Telephone: **CALthorpe 3114**

Udal PRESS GUARDS

VULCASCOT ANTI-VIBRATION PADS

OIL RESISTING

Improve *Production!*

- CHECK VIBRATION SHOCK AND NOISE
- COMBAT NERVOUS STRAIN
- ARE EASY TO INSTALL
- SAVE MAINTENANCE TIME AND COST
- ISOLATE LOADS UP TO 4 TONS PER SQ. FT.
- ELIMINATE CUMBERSOME FLOOR FIXINGS

Standard Size 18" x 18" x ½"

Manufactured by:

VULCASCOT (Great Britain) LTD.

87-89, ABBEY ROAD, LONDON, N.W.8.

PHONE: MAIDA VALE 7374 & 7375. 'GRAMS: VULCASCOT MAIDA VALE LONDON

Give it air . . .

HOT OR COLD

With

Secomak REGD

STATAIR BLOWERS

For HIGH VELOCITY Suction & Blowing

Compact and light. Several models available, air volumes up to 270 c.f.m. W.G. pressures up to 28" Write for Data Sheets 104&132/PE

SECOMAK

HEATER

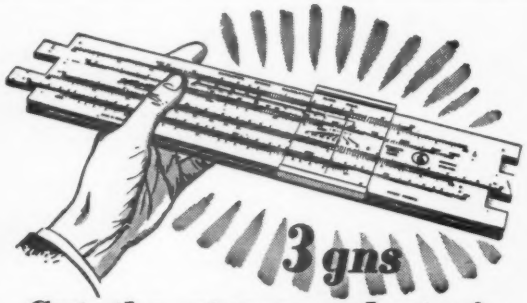
Attachments

Hot air at temperatures up to 700°F can be obtained by fitting "Secomak" Heater Attachments to Statair Units. Available in various sizes to fit all models. Used for many drying and heating processes. Write for Data Sheet 130/PE

SERVICE ELECTRIC CO. LTD.

HONEYPOT LANE · STANMORE · MIDDX.

Telephone EDGware 5566-9



3 gns

Cut the stress and strain from spring calculation

WITH A 'RATCLIFFE' SPRING CALCULATING SLIDE RULE

★ Scales allow all calculations involved in the design of helical tension and compression springs to be made at one setting!

★ Upper slide for stress and load calculations!

★ Wahl's stress correction calculated quickly!

★ The rule is essential to engineers and draughtsmen, is soundly constructed and supplied in a strong case complete with instructions.

★ Price £3. 3s. 0d. Send for one to-day.

J. S. Ratcliffe

The Spring Specialist

CRAWFORD SPRING WORKS ALLEN STREET ROCHDALE LANCS

THE AIRCRAFT DIVISION OF AIR SERVICE TRAINING LTD of HAMBLE
have found the O.M.T. 30" Projection Type Rotary Table
to be an invaluable auxiliary for fast, accurate production of a
wide range of Jigs, Tools and Components.

OMT **30" projection type rotary table**

READINGS DIRECT TO 1 SECOND OF ARC

POWER OPERATED PLATEN

WEIGHT CAPACITY 1200 lb.

DUAL SCREEN UNIT PERMITTING LOCATION OF WORKPIECES CONSIDERABLY IN EXCESS OF PLATEN SIZE

SETTING ACCURACY UNAFFECTED BY THE POWER DRIVE, CLAMPING OR LOAD

PRESETTING OF THE SCALE

A PRECISION PRODUCT OF
OPTICAL MEASURING TOOLS LTD
MAIDENHEAD BERKSHIRE

PLEASE ADDRESS ENQUIRIES TO :

NEWALL GROUP SALES LIMITED

PETERBOROUGH • TELEPHONE PETERBOROUGH 3227-8-9

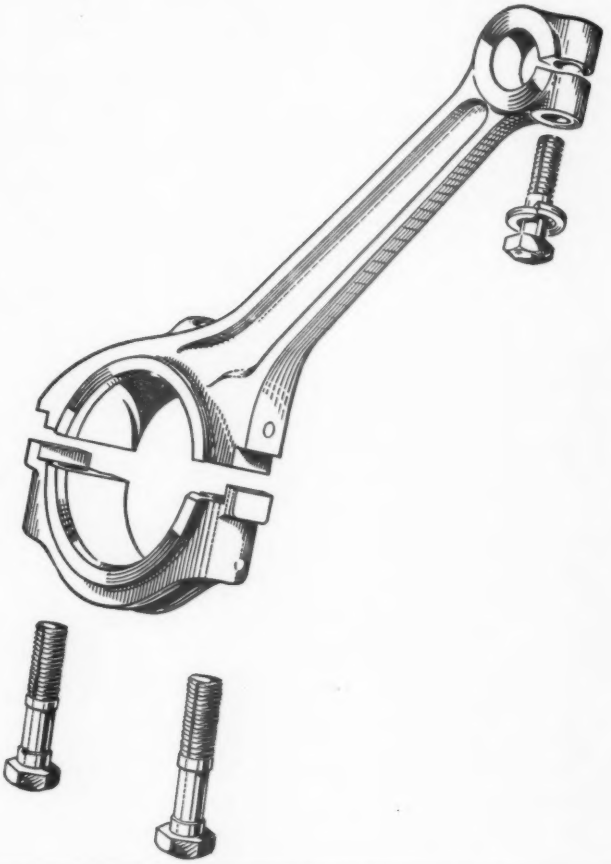
INDEX TO ADVERTISEMENTS

	Page
Acheson Colloids, Ltd.	—
Adcock & Shipley, Ltd.	vi
Aircraft Engineering & Jigs, Ltd.	—
Allen, Edgar & Co. Ltd.	ci
Archdale, James & Co. Ltd	lxxii
Armstrong Patents Co. Ltd.	lxxxiv
Arrow Electric Switches, Ltd.	lxxix
Asquith, William, Ltd.	xxx
Automatic Coil Winder & Electrical Equipment Co. Ltd., The	iv
Barber & Colman, Ltd.	—
Bawn, W. B. & Co. Ltd.	xcvi
Bedford, John, & Sons, Ltd.	lxxxiv
Benton & Stone, Ltd.	—
B.I.P. Chemicals, Ltd.	—
Birlec, Ltd.	lxxxix
Birmingham Aluminium Casting (1903) Co. Ltd.	iii
Black & Decker, Ltd.	xxxiii
Brammer, H. & Co. Ltd.	lxxx
Bratby & Hinchliffe, Ltd.	lxxviii
Bray Accessories, Ltd.	—
British Aero Components, Ltd.	xxix
British Electrical Development Association, The	l
British MonoRail Limited	—
British Oxygen Gases, Ltd.	xxxvii
British Thomson-Houston Co. Ltd.	—
British Timken Ltd.	—
Broadbent, Henry, Ltd.	xcvii
Brockhouse, J. & Co. Limited	—
Brookhirst Switchgear, Ltd.	—
Broom & Wade, Ltd.	—
Brown, David, Corporation (Sales) Ltd., The	lxxxvii
B.S.A. Tools, Ltd.	xxxix
Burton Griffiths & Co. Ltd.	xxxix
Butler Machine Tool Co. Ltd., The	xliv
Butterley Co. Ltd., The	liv
Carborundum Company Ltd., The	xv
Catmur Machine Tool Corporation, Ltd.	—
Cementation (Muffelite) Ltd.	—
Churchill, Charles & Co. Ltd.	lviii
Churchill Machine Tool Co. Ltd.	xlii
Cincinnati Milling Machines, Ltd.	xl
Clarkson (Engineers) Ltd.	lxxx
Climax Rock Drill & Eng. Works Ltd.	—
Concentric Manufacturing Co. Ltd.	xlvi
Coventry Climax Engines, Ltd.	*Outside Back Cover*
Coventry Gauge & Tool Co. Ltd.	xxv
Cow, P. B., Ltd.	—
Croda, Ltd.	lxxxii
Crofts (Engineers), Ltd.	lxvi
Crompton Parkinson, Ltd.	lxxxi
Darling & Sellers, Ltd.	—
Dawe Instruments, Ltd.	lxi
Dawson Bros., Ltd.	xxxvi
Dean Smith & Grace, Ltd.	xii
Denham's Engineering Co. Ltd.	—
Dowding & Doll, Ltd.	lvii
Drummond Asquith (Sales), Ltd.	xxxii
Drummond Bros., Ltd.	xxxi
Duckham, Alexander & Co. Ltd.	—
Durachrome, Ltd.	lxxxviii
Dyson & Co. Enfield (1919), Ltd.	—
Edibrac, Ltd.	lxxiv
Electro-Chemical Eng. Co. Ltd.	—
Electro-Dynamic Construction Co. Ltd.	lxix
Elgar Machine Tool Co. Ltd.	lxv
Elliott Brothers (London) Ltd.	—
E.M.S. Electrical Products, Ltd.	lxxxii
English Electric Co. Ltd., The	—
Exors of James Mills, Ltd.	—
Factory Equipment Exhibtion	—
Fawcett-Finney, Ltd.	—
Ferranti, Ltd.	—
Firth Brown Tools, Ltd.	—
Firth, Thos., & Brown, John, Ltd.	—
Flame Hardeners, Ltd.	c
Fletcher Miller, Ltd.	xciv
Fox Chemical Engineering Works, Ltd.	—
Fox, Samuel & Co. Ltd.	—
Fraser, Andrew & Co. Ltd.	—
Gledhill-Brook Time Recorders, Ltd.	lxxxviii
Glostics, Ltd.	lvi
G.P.A. Tools & Gauges, Ltd.	lxii
Graham & Normanton, Ltd.	—
Guest, Keen & Nettlefolds (Midlands), Ltd.	—
Guylee, Frank, & Son, Ltd.	lxxxvi
Harrison, T. S. & Sons, Ltd.	xciii
Harris Tools, John, Ltd.	—
Heenan & Froude, Ltd.	liii
Herbert, Alfred, Ltd.	—
Hilger & Watts, Ltd.	xc
Holman Bros., Ltd.	xxi
Hoover, Ltd.	lv
Hordern, Mason & Edwards, Ltd.	—
Horstmann Gear Co. Ltd., The	lxxvi
Howard, Stanley, Ltd.	x
Hymatic Engineering Co. Ltd., The	—
Igranic Electric Co. Ltd.	—
Imperial Smelting Corporation (Sales), Ltd.	xxvii
Impregnated Diamond Products, Ltd.	xlix
Integra, Leeds & Northrup, Ltd.	—
Intermit, Ltd.	xcii
Jessop, Wm. & Sons, Ltd.	xci
Johansson, C. E., Ltd.	xcix
Jones, E. H. (Machine Tools), Ltd.	—
Jones, Sidney G., Ltd.	lxiii
King, Geo. W., Ltd.	lix
Kirkstall Forge Engineering, Ltd.	lxxxv
Lang, John & Sons, Ltd.	xlv
Lang Pneumatic, Ltd.	xcv
Lansing Bagnall, Ltd.	—
Lapointe Machine Tool Co. Ltd., The	li
Ley's Malleable Castings Co. Ltd.	—
Lincoln Electric Co. Ltd., The	—
Lloyd, F. H. & Co. Ltd.	—
Lloyd, Richard, Ltd.	xcviii
London Oil Refinery Co. Ltd., The	—
Lund, John, Ltd.	lxxiii
Machine Shop Equipment, Ltd.	viii
Machinery Publishing Co. Ltd.	—
Macready's Metal Co. Ltd.	xx
Magnesium Elektron, Ltd.	—
Manganese Bronze & Brass Co. Ltd.	xxxv
Marbaix, Gaston E., Ltd.	—
Markland Scowcroft, Ltd.	lxxiv
Marsh, Bros., & Co. Ltd.	xcviii
McKechnie Bros., Ltd.	—
Mechanical Handling	lxvii
Metal Industries Group	—
Metal & Plastic Compacts, Ltd.	—
Metropolitan-Vickers Electrical Co. Ltd.	—
Midland Iron Co. Ltd., The	—
Mining & Chemical Products, Ltd.	—
Mitchell, D., & Co. Ltd.	v
Mollart Engineering Co. Ltd., The	—
Monks & Crane, Ltd.	vii
Morris, B. O., Ltd.	xi
Morrison, Marshall & Hill, Ltd.	—
Neill, James, & Co. (Sheffield), Ltd.	xxxviii
Newall, A. P. & Co. Ltd.	lxxvi
Newall Group Sales, Ltd.	xli, ciii
Norton Grinding Wheel Co. Ltd.	—
Park Gate Iron & Steel Co. Ltd.	*Inside Back Cover*
Parkinson, J., & Son (Shipley), Ltd.	—
Paterson Hughes Engineering Co. Ltd.	—
Physical Society, The	xx
Pilot Works, Ltd.	xcii
Pinder, W. & Son, Ltd.	c
Precision Grinding, Ltd.	lxx
Press Equipment, Ltd.	—
Proctor Bros. (Wireworks), Ltd.	—
Pryor, Edward, & Son, Ltd.	—
Quasi-Arc, Ltd.	xxxiv
Rack Engineering, Ltd.	xiv
Radio Heaters, Ltd.	—
Ransomes, Sims & Jefferies, Ltd.	c
Ratcliffe, F. S., (Rochdale), Ltd.	cii
Reavell & Co. Ltd.	lxxxvi
Redfern's Rubber Works, Ltd.	—
Rediffusion, Ltd.	—
Reliance Gear & Eng. Co. (Salford), Ltd.	—
Rockwell Machine Tool Co. Ltd., The	—
Rushworth & Co. (Sowerby Bridge), Ltd.	—
Russell, S. & Sons, Ltd.	—
Ryder, Thos. & Son, Ltd.	lxxxiii
Saville, J. J. & Co. Ltd.	xci
Scrivener, Arthur, Ltd.	—
Selson Machine Tool Co. Ltd., The	lxxi
Sentinel (Shrewsbury), Ltd.	—
Service Electric Co. Ltd.	cii
Shell-Mex & B.P., Ltd.	xiii
Sheepbridge Equipment, Ltd.	xcvi
Skinners, (Redbridge), Ltd.	—
Smart & Brown Machine Tools, Ltd.	—
Snow & Co. Ltd.	lx
Société Genevoise, Ltd.	xvii, xviii, xix
Sogenique (Service), Ltd.	—
Sparcatron	lxiv
Sparklets, Ltd.	—
Spencer & Halstead, Ltd.	—
Sternol, Ltd.	—
Sunbeam Anti-Corrosives, Ltd.	lxxv
Swales, C. A., (Filters), Ltd.	—
Swift, Geo. & Sons, Ltd.	—
Swift-Summerskill, Ltd.	lxxviii
Sykes, W. E., Ltd.	xlvii
Taylor, Taylor & Hobson, Ltd.	—
Teleflex Products, Ltd.	xc
Town, Frederick & Sons, Ltd.	xlviii
Turner Machine Tools, Ltd.	—
Udal, J. P., Ltd.	cii
Unbrako Socket Screw Co. Ltd.	ix
United Steel Companies, Ltd., The	—
Universal Tools, Ltd.	—
Van Moppes & Sons (Diamond Tools), Ltd.	lii
Victrolec, Ltd.	xxxvi
Vulcascot (Great Britain), Ltd.	cii
Wadkin, Ltd.	xciv
Ward, H. W., & Co. Ltd.	xliii
Ward, Thos. W., Ltd.	lxxvii
Webster & Bennett, Ltd.	xvi
Westool, Ltd.	lxviii
Whyte & Collins, Ltd.	—
Wickman. Ltd.	xxii, xxiii, xxiv, xxvi
Wild-Barfield Electric Furnaces, Ltd.	xxviii
Woodhouse & Mitchell	—
Wolverhampton Die Casting Co. Ltd., The	—

All communications regarding advertisements should be addressed to the Advertising Managers, T. G. Scott & Son, Ltd.
Crown House, 143-147, Regent Street, London, W.1. Phone: Regent 3891.
Printed by Maxwell, Love & Co. Ltd., White Lion Street, London, N.1.

PARK GATE

QUALITY STEELS FOR DROP FORGINGS



1823 EXPERIENTIA DOCET 1956

black bars

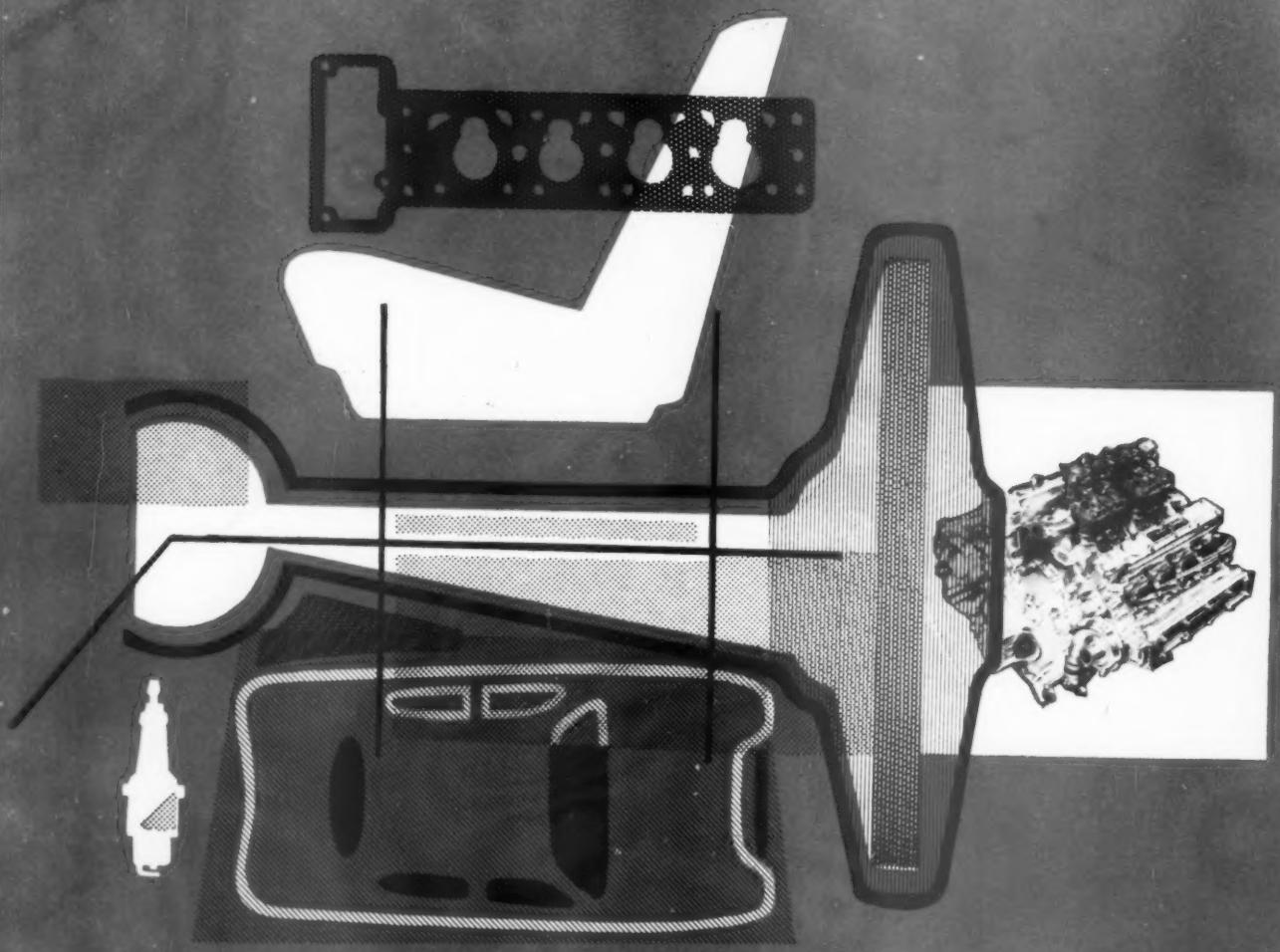
for

connecting rods

THE PARK GATE IRON and STEEL COMPANY LIMITED ROTHERHAM

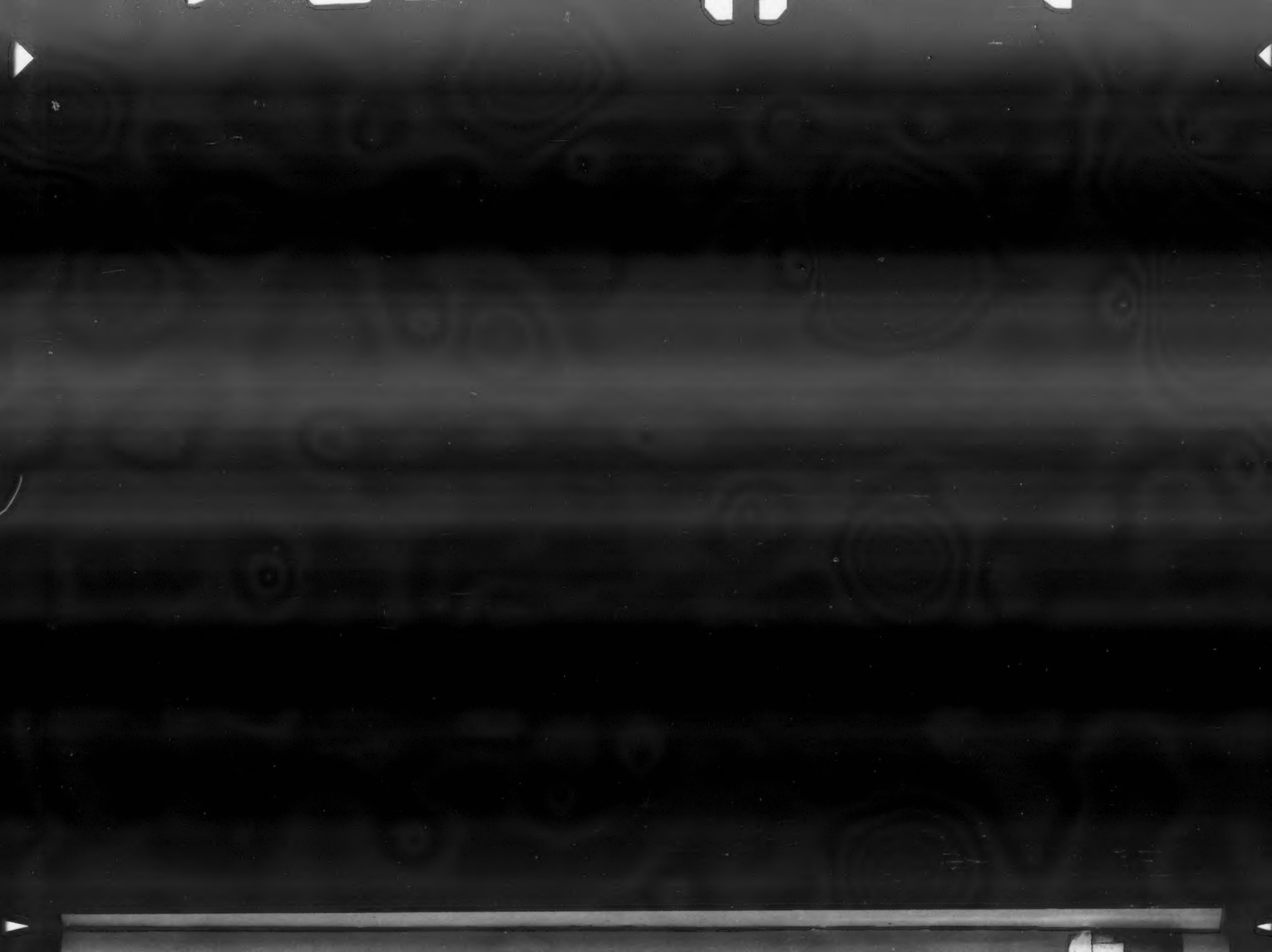
TELEPHONE ROTHERHAM 2141 (10 lines) TELEGRAMS: YORKSHIRE PARKGATE. YORKS

The MOTOR INDUSTRY



Most highly mechanised of all industries — the Motor Industry makes extensive use of the cost cutting

Coventry Climax

FORK LIFT TRUCKS

Coventry Climax Engines Ltd. (Dept. IPJ), Coventry, England